Ames

IN-22086

NASA CONTRACTOR REPORT 177378

Advanced Life Support Control/Monitor Instrumentation Concepts for Flight Application

D. B. Heppner
M. J. Dahlhausen
R. B. Fell

(NASA-CR-177378) ADVANCED LIFE SUPPORT CONTROL/MONITOR INSTRUMENTATION CONCEPTS FOR FLIGHT APPLICATION Final Report, Nov. 1983 - Jun. 1985 (Life Systems) 73 p CSCL 05H

N88-26807

Unclas
G3/54 0022086

CONTRACT NAS2-11758
March 1986

NASA

NASA CONTRACTOR REPORT 177378

Advanced Life Support Control/Monitor Instrumentation Concepts for Flight Application

D. B. Heppner, M. J. Dahlhausen
and R. B. Fell
Life Systems, Inc.
Cleveland, Ohio

Prepared for
Ames Research Center
under Contract NAS2-11758

March 1986

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

FOREWORD

The development work described herein was conducted by Life Systems, Inc. at Cleveland, Ohio under Contract NAS2-11758, during the period of November, 1983 through June, 1985. The Program Manager was Dr. Dennis B. Heppner. The personnel contributing to the program and their responsibilities are outlined below:

Personnel	Area of Responsibility
Michael J. Dahlhausen	Performance Diagnostic Unit Design, Hardware Selection, Software Fabrication and Test
Roger B. Fell	Generic Sensor Signal Conditioning Concept Evaluation and Design
Dennis B. Heppner, Ph.D.	Program Manager, System Design and Analysis
Rick A. Wynveen, Ph.D.	Control and Monitor Concept Evaluation, Operator/System Interface Requirements

The contract's Technical Monitor was Dr. T. Wydeven, Advanced Life Support Office, National Aeronautics and Space Administration Ames Research Center, Moffett Field, CA.

TABLE OF CONTENTS

continued-

Table of Contents - continued

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

A/D	Analog to Digital Converter
ARC	Ames Research Center
ARS	Air Revitalization System
B-CRS	Bosch CO_2 Reduction Subsystem
BIU	Bus Interface Unit
C/M I	Control/Monitor Instrumentation
CMOS	Complementary Metal Oxide Semiconductor
CPU	Central Processing Unit
CRT	Cathode Ray Tube
CS-3A	Three-Person EDC
D/A	Digital to Analog Converter
DARS	Data Acquisition and Reduction System
DMS	Data Management System
ECLSS	Environmental Control/Life Support System
EDC	Electrochemical Depolarized CO_2 Concentrator
EEPROM	Electronically Erasable Programmable Read-Only Memory
EMI	Electromagnetic Interference
EPROM	Eraseable Programmable Read-Only Memory
FET	Field-Effect Transistor
IC	Integrated Circuit
I/O	Input/Output
LED	Light Emitting Diode
LVDT	Linear Variable Differential Transformer
MTBF	Mean-Time Between Failures
MUX	Multiplexer
µP	Microprocessor
NASA	National Aeronautics and Space Administration
NSS	Nitrogen Supply Subsystem
OGS	Oxygen Generation Subsystem
PC	Printed Circuit
PDU	Performance Diagnostic Unit
PGIA	Programmable Gain Instrumentation Amplifier
RAM	Random Access Memory
RF	Radio Frequency
RFI	Radio Frequency Interference
RTD	Resistance Thermal Device
S/C	Signal Conditioning
S-CRS	Sabatier Carbon Dioxide Reduction Subsystem
TCS	Thermal Control System
TSA	Test Support Accessories
TTL	Transistor-Transistor Logic
VCDS	Vapor Compression Distillation Subsystem
WRS	Water Recovery System

SUMMARY

Development of regenerative Environmental Control/Life Support Systems requires instrumentation characteristics which evolve with successive development phases. As the development phase moves toward flight hardware, the system availability becomes an important design aspect which requires high reliability and maintainability. As part of a continuing development effort, a program to evaluate, design and demonstrate major advances in two key areas of control and monitor instrumentation was undertaken by Life Systems. This program was directed toward instrumentation designs which incorporate features compatible with anticipated flight requirements.

The first task consisted of the design, fabrication and test of a Performance Diagnostic Unit. It assembles into one unit the operator/system interface capabilities removed from the Series 100 of advanced life support system instrumentation as part of its evolution into the Series 200 and additional capabilities needed for flight application. This unit shall ultimately function as a portable diagnostic unit able to interface with each of the projected systems or subsystems of the advanced life support processes. In interfacing with a subsystem's instrumentation, the Performance Diagnostic Unit is capable of determining faulty operation and components within a subsystem, perform on-line diagnostics of what maintenance is needed and accept historical status on subsystem performance as such information is retained in the memory of a subsystem's computerized controller. The unit was built, designed, configured and tested to interface with an Electrochemical Carbon Dioxide Removal Subsystem.

The second focus of this program was development and demonstration of analog signal conditioning concepts which reduce the weight, power, volume, cost and maintenance and improve the reliability of this key assembly of advanced life support instrumentation. The approach was to develop a generic set of signal conditioning elements or cards which can be configured to fit various subsystems. Four generic signal conditioning cards were identified as being required to handle more than 90% of the sensors encountered in life support systems. Under company funding, these were detail designed, built and tested. They were then successfully demonstrated and will soon be applied to a system undergoing development.

INTRODUCTION

As flight application for advanced life support systems approaches, the need for demonstrating the maturity of the technology is essential. Unless such effort is undertaken, the country's Space Station will be developed with obsolete technology in the life support area.

An important system of the Space Station is the Environmental Control/Life Support System (ECLSS). The Space Station ECLSS should be based on regenerative techniques in the areas of air revitalization and water recovery. Regenerative life support systems are processes in the conventional sense and, therefore, require process instrumentation. Such instrumentation includes provisions for control and monitoring of the processes.

Background

Today's Control/Monitor Instrumentation (C/M I) is based on computer technology. The regenerative Air Revitalization System (ARS) and, to a lesser degree, the Water Recovery System (WRS) C/M I's have been developed under the sponsorship of the National Aeronautics and Space Administration (NASA), specifically the Ames Research Center (ARC). These activities resulted in the development of the Series 100 C/M I.[1] It was utilized for such subsystems as the Electrochemical Carbon Dioxide (CO_2) Removal Subsystem (EDC),[2,3] Vapor Compression Distillation Subsystem (VCDS), Oxygen (O_2) Generation Subsystem (OGS),[4] etc. (see Figure 1). Specific ARC instrumentation developments include those under Contracts NAS2-9251, NAS2-10050 and NAS2-10674.

An overall ECLSS instrumentation development program objective is to reduce size and to increase system availability (reliability and maintainability). The goal is to ready the ECLSS C/M I for the Space Station missions. Figure 2 shows the two dimensions of the advanced C/M I R&D thrust. One is the development thrust toward the flight hardware C/M I. It is projected that this development will go through perhaps three generations with the Series 100 being the first for laboratory breadboard ECLSS hardware development and testing. The next generation, Series 200, is dedicated to prototype hardware. Finally, the Series 300 will be used for flight hardware applications. It is envisioned that Series 200 hardware could become Series 300 flight hardware with a minimum of upgrade to satisfy qualification rigor requirements. Examples would include packaging for vibration and use of high-reliability, military specification components.

The common Series 100 C/M I was developed incorporating the electronics and instrumentation advancements generated under prior development efforts. In particular, this instrumentation provided for operator/system interfacing that had never been implemented before and at a convenience level that had been heretofore impossible. These developments included incorporation of a Cathode Ray Tube (CRT) for visual indication of process performance and fault diagnostic information. It also incorporated a dedicated and customized keyboard for rapid interrogation of the memory of the C/M I for the performance data, operating setpoints and conditions, as well as convenience for changing operating conditions. The latter is very important during advanced subsystem development efforts.

In the evolution of the advanced life support systems flight C/M I capability, the operator/system portions were duplicated in each of the C/M I's built for the various systems and subsystems. These included:

1.	Model 110	Integrated ARS
2.	Model 120	EDC
3.	Model 130	Sabatier CO_2 Reduction Subsystem (S-CRS)
4.	Model 140	VCDS (water recovery)
5.	Model 150	Bosch CO_2 Reduction Subsystem (B-CRS)

(1) References cited at end of this report.

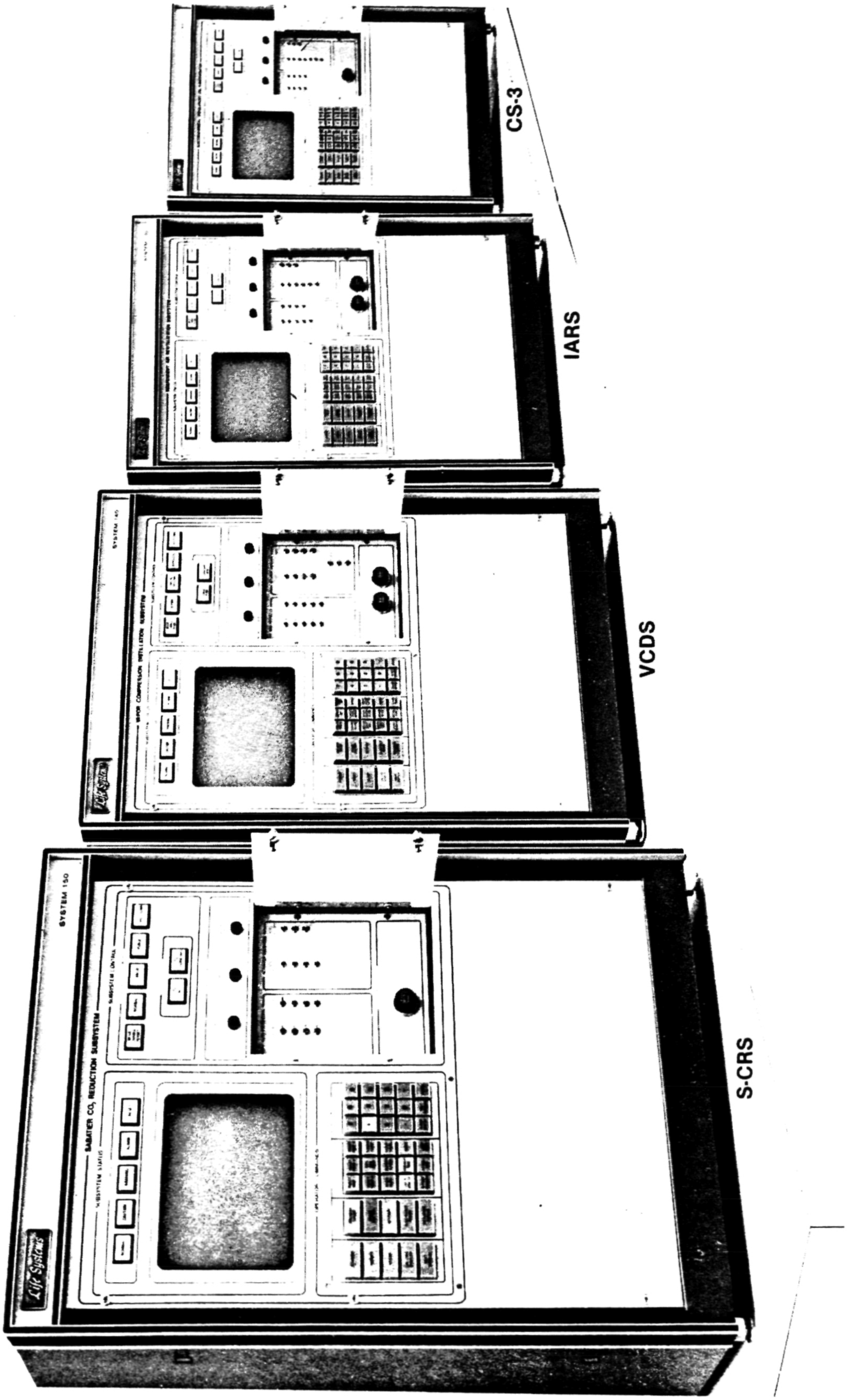
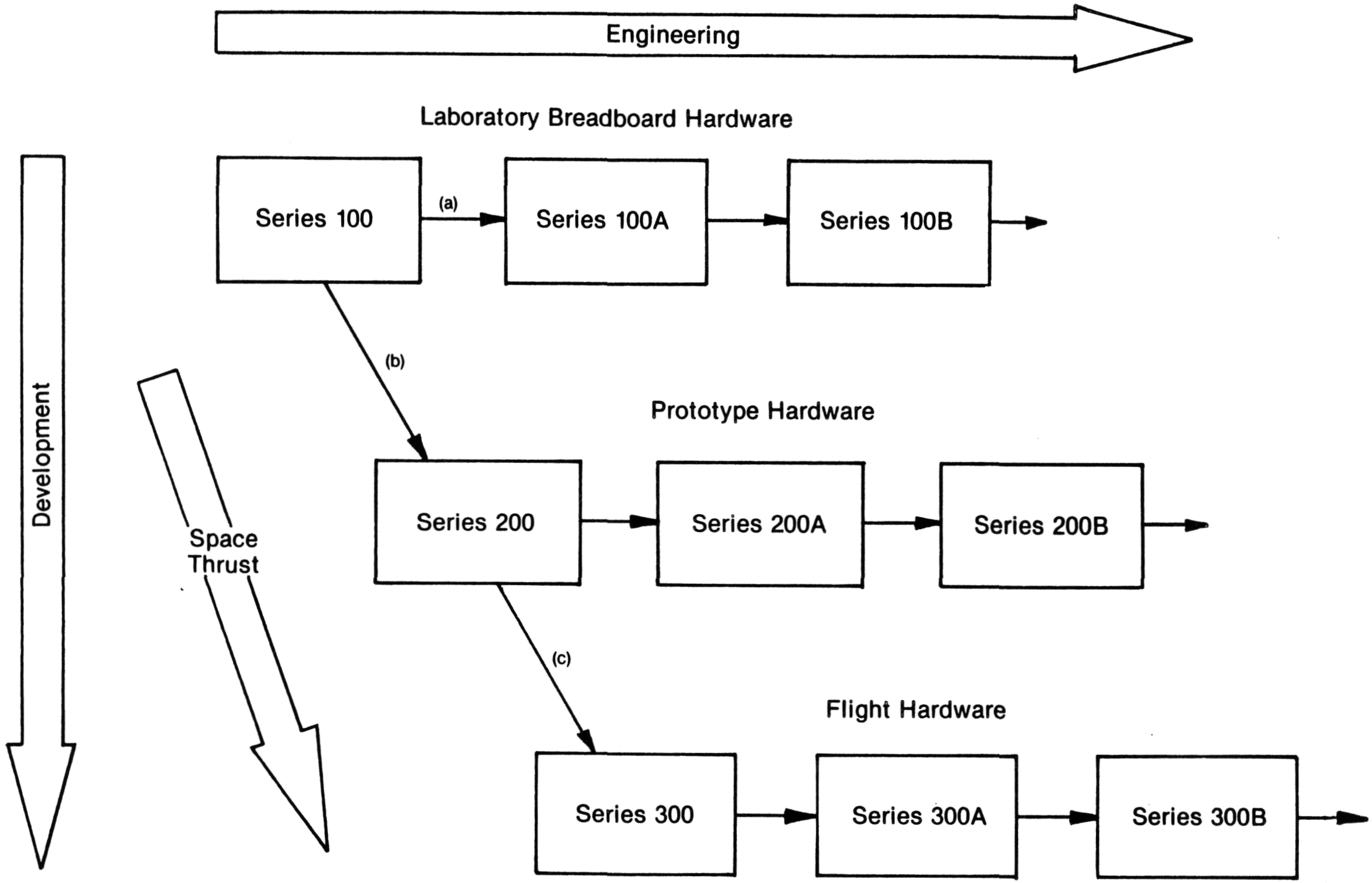


FIGURE 1 SERIES 100 C/M I FOR NASA'S ECLSS PROGRAMS



(a) Improve quality, eliminate weak links and increase capability.
(b) Increase capability per unit size, reduce flexibility and incorporate new components and concepts. Increase availability per unit size.
(c) Satisfy flight qualification requirements.

FIGURE 2 ALSS C/M I DEVELOPMENT

6. Model 160 OGS
7. Model 170 Nitrogen Supply Subsystem (NSS)
8. Model 190 Regenerative Fuel Cell System (RFCS)

Thus it can be seen, the Ames instrumentation development programs cited above have contributed significantly to the advancing of multiple ECLSS technology efforts by the development of a generic type C/M I.

During use of the Series 100 developments it was realized flight application would not require each subsystem to have its own operator/system interface. Thus, under Contract NAS2-10674, those portions common to each of the above C/M I models that relate to the operator/system interface were removed leaving a considerably more flight-oriented size that still retained the commonality instrumentation features. Specific items deleted included the CRT, CRT controller, dedicated keyboard, override switches and manual controls for varying specific operating parameters (e.g., O_2 generation rate). The results of the NAS2-10674 development was a new ARC milestone, the Series 200 C/M I design.[5-8] Figure 3 shows the comparison of Series 100 and 200 C/M I.

The deletion of the operator/system interface required that it be replaced by a separately housed capability to provide the function. This was done under the current program and is referred to as the Performance Diagnostic Unit (PDU).

Further reductions of size of the Series 200 C/M I and increased reliability were envisioned in the signal conditioning (S/C) area. The S/C assembly forms a large portion (40%) of the Series 200. A new approach to S/C was investigated under the current program.

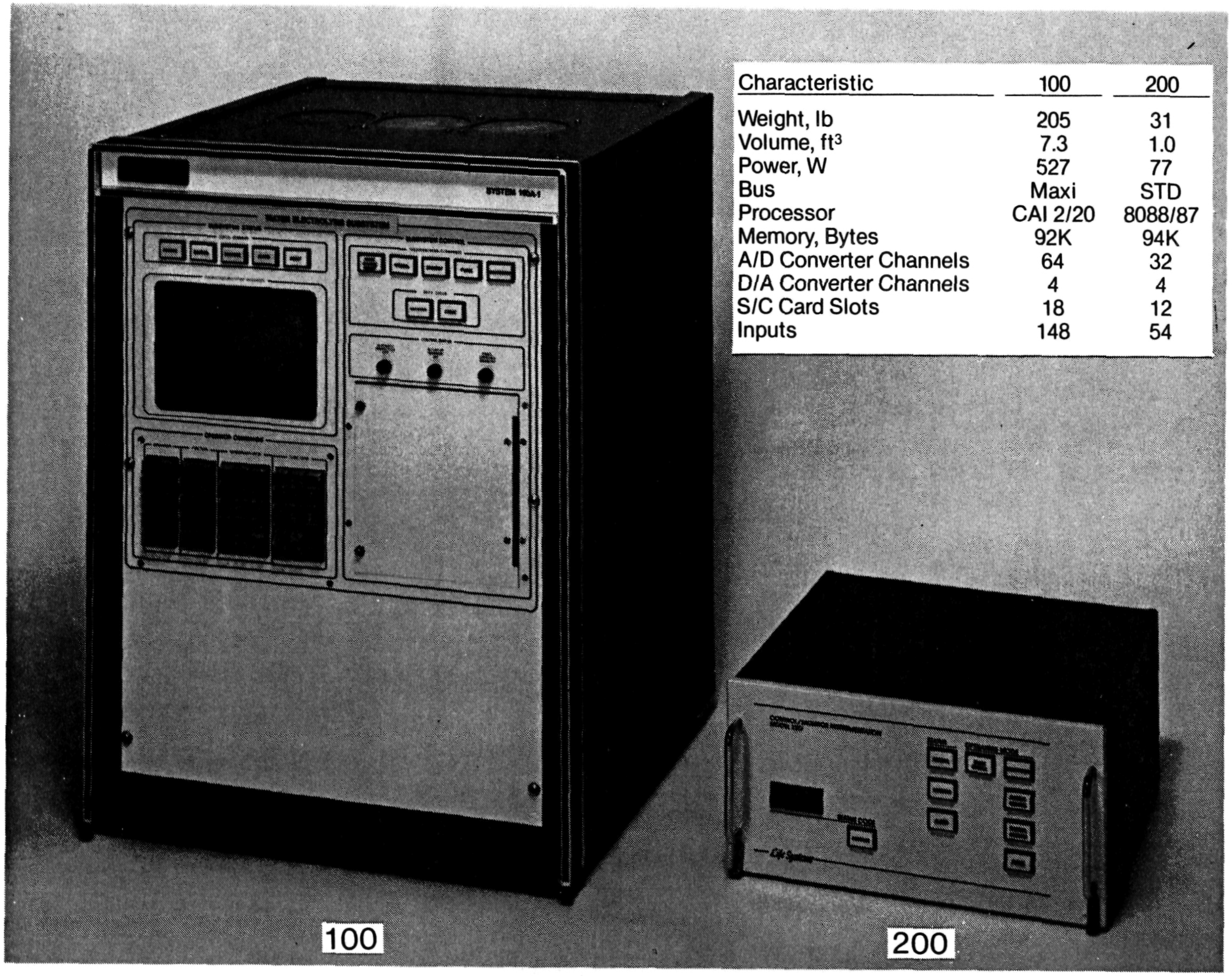
Program Objectives

The objectives of the current program were to provide two major advances in ECLSS instrumentation technology. The first was to develop a functional electronic unit that assembles into one enclosure, most of the operator/system capabilities removed in passing from the 100 to the 200 Series. The second objective was to reduce a major assembly of the C/M I that, heretofore, has undergone little evolutionary change over the past designs. Specifically, the analog S/C has remained virtually the same since many of the circuits were identified as being needed and designed 10 to 15 years ago.

This Final Report covers the work performed to meet the above objectives during the period November, 1983 through June, 1985. The following two major sections present the technical results according to (1) the PDU and (2) Generic S/C. These sections are followed by Conclusions based on the work performed.

PERFORMANCE DIAGNOSTIC UNIT

This section of the Final Report describes the development work on the PDU. It is broken into the following subsections: design requirements, hardware design, software design and end-item description.



Characteristic	100	200
Weight, lb	205	31
Volume, ft^3	7.3	1.0
Power, W	527	77
Bus	Maxi	STD
Processor	CAI 2/20	8088/87
Memory, Bytes	92K	94K
A/D Converter Channels	64	32
D/A Converter Channels	4	4
S/C Card Slots	18	12
Inputs	148	54

FIGURE 3 COMPARISON OF 100 AND 200 SERIES CONTROLLERS

Design Requirements

The overall design requirement of the PDU was to assemble into one unit the operator/system interface capabilities that were removed from the Series 100 advanced life support subsystem instrumentation as part of its evolution into the Series 200 and incorporate additional capabilities needed for flight application. To this end, design guidelines, hardware goals and interface requirements were established.

Design Guidelines

Table 1 presents the overall design guidelines of the PDU. The choice of standard commercially available hardware components was done for cost purposes. Flight hardware equipment, even if available, would have been prohibitively expensive for this program.

Portability of software was a key guideline to ensure that the PDU software is "generic" to the maximum extent possible. That means it's not tied either to specific hardware nor to a particular application.

Hardware Goals

The hardware goals were divided into four categories as given in Table 2: performance, operation, operating feature and packaging goals. Ease of operator use and maintenance were important operating feature goals. Also compatibility with existing Series 200 and projected Series 300 C/M Is was required. The STD computer bus was selected to ensure a wide range of vendor sources for the computer cards and not to be locked into a specific vendor's own bus that might not be supported in the future.

Space Station Interfaces

The PDU is projected to interface with the following Space Station systems:

1. ECLSS
2. Data Management System (DMS)
3. Electrical Power Distribution System
4. Command Center
5. Thermal Control System (TCS)

The following subsections describe these interfaces which are summarized in Table 3.

Environmental Control/Life Support System. The PDU will interface to the ECLSS C/M I at the subsystem level. This interface will require an interface standard that provides a means of two-way digital data transmission. The prototype will utilize the RS-232C, serial asynchronous interface standard for demonstration purposes. The MIL-STD-1553B standard may be selected for Space Station. Either interface will have the data and command capability shown in Table 4.

TABLE 1 DESIGN GUIDELINES

1. Minimize weight, volume, power and maintainability.

2. Maximize reliability.

3. Use standard commercial parts whenever possible - to save development time, cost and the need for expensive testing to prove "new design" reliability.

4. Ensure that the PDU does not inhibit or otherwise affect the Control/Monitor Instrumentation from performing its function.

5. A structured software design that promotes the independence and portability of software modules, thereby producing code that can be used in future systems.

6. A software design that structures the application software package into individual modules. Each module shall be constructed to work with other modules, but to be independent of the internal structure and local data of the other modules.

7. The development of software documentation that evolves concurrently with the software design.

8. A "top-down" developmental strategy. This will promote early hardware/ software integration and operation of developed software.

TABLE 2 PDU GOALS

Performance Goals	
1. Response Time	<2 sec (Worst Case)
2. Startup Time	<10 sec
3. Data Display	Engineering Units
4. Message Blocking	Automatic[a]
5. Message Length	Variable
6. Touch Temperature	<322 K (120 F)
7. Cooling	Forced Air
8. Operating System	Real-Time, Multitasking
9. Software Structure	Expandable
10. Arithmetic Capability	Floating Point, Hardware Co-processor
Operation Goals	
1. Expendables	None (Except Electrical Power)
2. Compatibility	Series 200 and 300 C/M I
3. Operating Environment	Space Station Temperature, Pressure, RH
4. Materials of Construction	Per NASA NG13 8060.1 and SE-R-0006A
5. Calibration	Needed Infrequently and Readily Performed
6. Communication Interface	RS-232C
7. Noise	Less than 60 Decibels
8. Operation	Continuous
9. Printer Interface	Centronics Parallel

continued-

(a) Performed by computer.

Table 2 - continued

Operating Feature Goals	
1. User Interface (Input)	Keyboard, 89 Keys
2. User Interface (Output)	CRT, BW, 80 Columns x 24 Lines
3. Computer Interface	Series 200 and 300 C/M I
4. Command Structure	English-Like
5. No. Menu's	<8
6. User Definable Keys	≤17 Keys
7. Peripherals	Printer, Modem[(a)]
8. User Interface	Interactive, Supported by Help and Error Messages
9. Time Base	Clock/Calendar Time
Packaging	
1. Configuration	Self-Contained
2. Maintainability	To the Assembly (e.g., CRT) or PC Level
3. Weight	<15.9 kg (35 lb)
4. Volume	<36 x 53 x 58 cm (14 x 21 x 23 in) Including Keyboard
5. Power	115 VAC, 60 Hz, 100 W max with Auxiliary 3 A Switched AC Outlet
6. Reliability	0.9999
7. Operating Life	6 yr
8. Shelf Life	10 yr
9. Computer Bus	STD
10. Card Cage	13.3 x 48.3 x 21.6 cm (5.25 x 19 x 8.5 in) with Detachable Cover and 16 Card Capacity

(a) Provisions for.

TABLE 3 PDU PROJECTED INTERFACES

ECLSS	
Communication Standard	RS-232C
Type	Serial, Asynchronous
Transmission Rate	Selectable (110-9,600 Baud)
Command Center[a]	
Output (Visual)	CRT -30 cm (12 in) BW
Input (Tactile)	Keyboard (89 Keys)
Hard Copy	Printer
Data Management System	
Interface	Bus Interface Unit[b]
Communication Standard	MIL-STD-1553B[b]
Type	Serial, Asynchronous[b]
Transmission Rate	768 k baud (max)
Power, W[a]	
AC (115 VAC, 60 Hz, 1Ø)[c]	$\leq$100
Heat, W[a]	
Load	$\leq$100
Other	
Gravity	0-1
Surface Touch Temperature, K (F)	322 (120)

(a) Characteristics based on preprototype.
(b) Projected as a candidate implementation.
(c) Actual flight application would use Space Station power, i.e., 28 VDC.

TABLE 4 PDU DATA AND COMMAND CAPABILITY

A. The PDU can display data. The data that can be displayed is:

1. The value of all actuators in engineering units (e.g., current flowing to EDCM, pump is on/off).

2. The value of all actuator overrides in engineering units and the override status. The actuator override status indicates if a specific actuator is under C/M I control or under user control at a specified value.

3. The value of all sensors in engineering units.

4. The value of all sensor overrides in engineering units and the status of these overrides. The sensor override status indicates if the C/M I will retrieve the value of a sensor from the physical sensor or a user specified value from C/M I memory; also whether fault detection on a sensor is overridden.

5. The subsystem status (normal, warning, alarm).

6. The subsystem present mode of operation (normal, shutdown, standby, etc.), the previous subsystem mode of operation, and the current mode transition, if any (e.g., shutdown to normal transition, normal to purge transition).

7. The setpoint information for all sensors, for all modes of operation (e.g., T1 normal mode high alarm is 304 K (88 F).

8. The values of all system timers. System timers indicate elapsed time for parameters. Examples of parameters are: the time in normal mode of operation, total time on a pump or other rotating component, time since last purge.

9. The parameters of all process loops. The parameters include desired setpoint, actual setpoint, frequency at which process loop executes, scale and gain factors, and intermediate calculations. Intermediate calculations are a good indicator of the dynamic performance of the process loops.

10. The individual status of each sensor in a subsystem (e.g., T1 is in warning, B1 is in alarm, all others normal). In addition to individual status, the state of the redundant sensors is given (i.e., voting, not voting, or if status has returned to normal).

11. The status of fault detection on all sensors, whether fault detection of a sensor(s) is enabled or disabled.

continued-

Table 4 - continued

12. The tolerance values of triple redundant sensors used by the triple redundant voting logic to determine if sensors values agree or not.

B. The PDU can change data. The data that can be changed is:

1. The value of all actuator overrides.

2. The value of all sensor overrides.

3. Any selected parameters of any process loop.

4. The computer interface channel assignments for sensors and actuators. For example, T1 will now be available on channel 2 of A/D board 1.

5. The value of all setpoints for any mode of operation.

C. The PDU can send user requests. The requests supported are:

1. Disable or enable fault detection on selected sensors.

2. Override selected actuators with user specified data.

3. Override selected sensors with user specified data.

4. Request a mode transition.

5. Activate a control routine with a new setpoint or control parameters.

Data Management System (DMS). The PDU is projected to interface with the DMS data processing and data handling functions. The nature of the information transferred between the PDU and the DMS is projected to include current operational parameters, historical and trending data, operational health and operational status of both the ECLSS instrumentation and the PDU. It is projected that the PDU shall connect to the DMS through a standard Bus Interface Unit (BIU). This BIU fulfills the DMS network operational and functional requirements.

Electrical Power Distribution System. As Table 3 shows, the PDU will require approximately 100 W (max) of electrical power. The prototype will utilize 115 VAC, 60 Hz, power as opposed to the power that the Space Station's electrical power distribution system will supply. It is projected that the flight version of the PDU will be a portable unit; hence provisions for recharging and energy storage are required. The flight version is projected to be supplied from 28 VDC.

Command Center. The PDU will have a Command Center interface. This is projected to consist of a display device for data output, and a data entry device for data input. The prototype unit will utilize a black and white, 30 cm (12 in) CRT display, and an 89 key, terminal keyboard. The interface shall be human engineered, utilizing menus, English-like command structure, display formats, messages, and user definable keys to aid a capable but untrained operator.

Thermal Control System. The Space Station thermal control system shall provide heat removal of the PDU. This is a need for collecting, transporting, and rejecting waste heat. The prototype will create a heat load of 100 W maximum, with thermal control provided by forced air cooling. Convective cooling is projected for Space Station application.

Hardware Design

Overall characteristics and arrangement of the PDU is shown in Figure 4. Basically it consists of a 30 cm (12 in) black and white CRT display and a standard operator's keyboard for interface with the operator/user. A black and white CRT was selected because the high resolution graphics capability that can be obtained as opposed to color. The CRT and keyboard are supported with both a floppy and hard disk drive for storage of programs and data. Communication interfaces will permit the connection of the PDU with peripheral devices such as printer, colored CRT and the C/M I through an RS-232C communication port.

Overall Structure

Figure 5 shows the overall hardware block diagram. There are five major assemblies in the PDU:

1. STD bus computer card cage containing the microprocessor card along with support cards. The STD bus is the microprocessor bus chosen to integrate the computer cards into the PDU hardware. A STD bus card

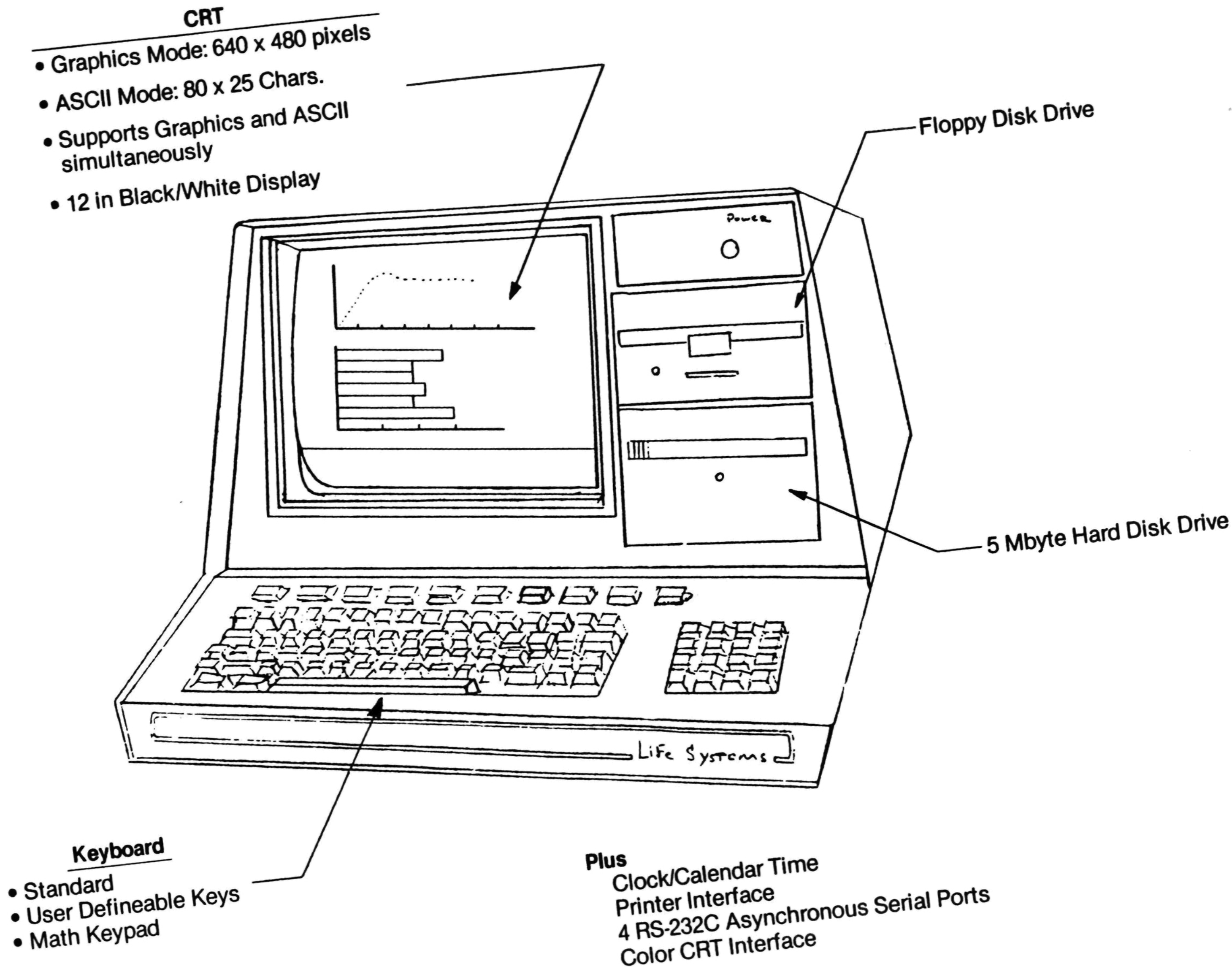


FIGURE 4 PERFORMANCE DIAGNOSTIC UNIT DESIGN

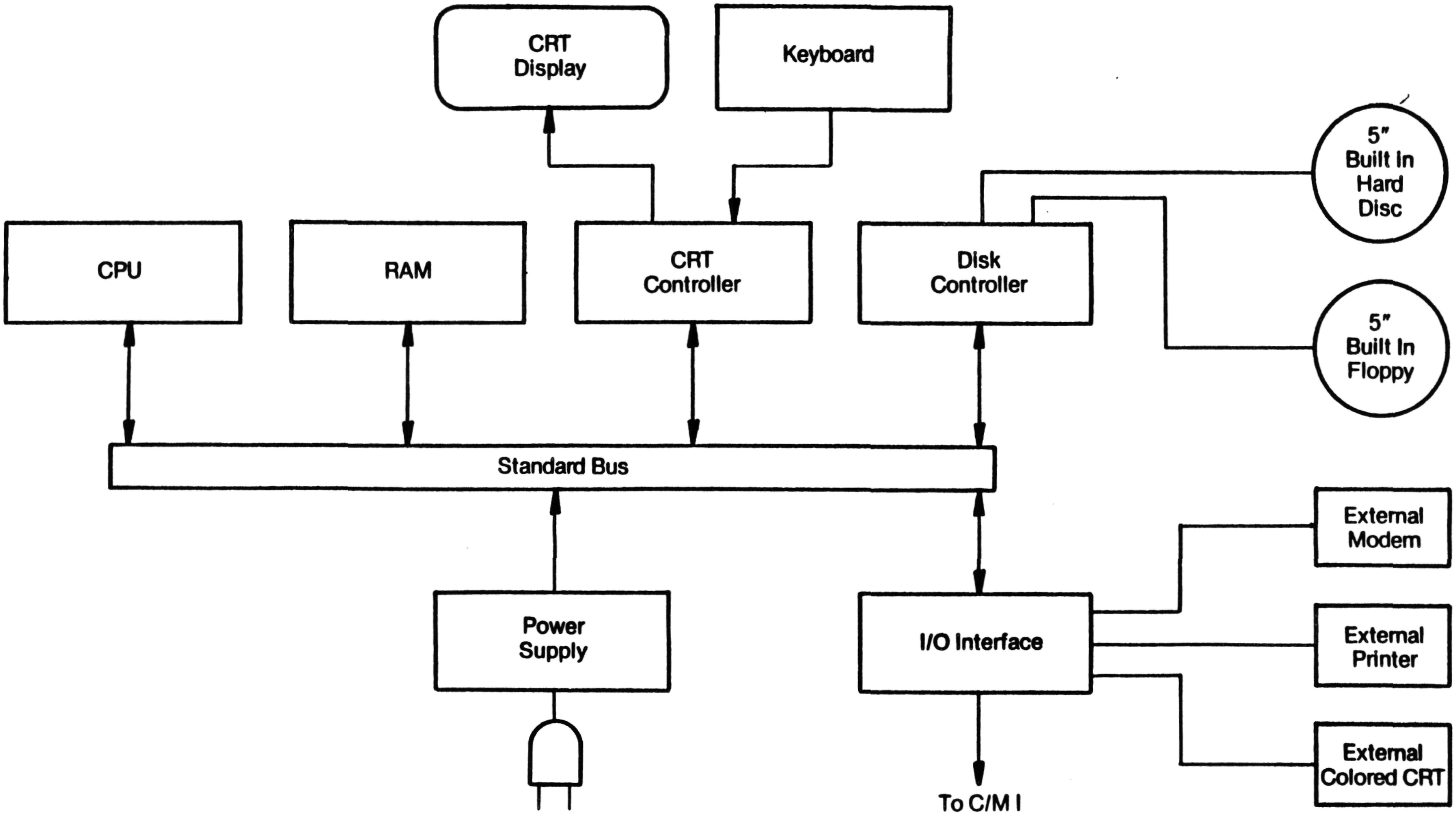


FIGURE 5 PDU HARDWARE BLOCK DIAGRAM

rack is an integral portion of the enclosure. Eight STD printed circuit (PC) cards available from a range of vendors were selected to perform the computer function. These are listed in Table 5. The STD bus card rack is an integral portion of the enclosure which also features chassis, power supplies, the CRT and detachable keyboard.

The PDU hardware design is based on a 16-bit microprocessor family. The PDU microprocessor, is supported by a firmware co-processor which provides floating point math capability. A programmable interrupt controller provides eight level interrupt arbitration and a programmable timer provides time-based generation. These components are integrated on a single 11.2 x 16.5 cm (4.4 x 6.5 in) STD card.

Program memory storage of 64K bytes is provided by eight eraseable programmable read only memory (EPROM) chips and 64K bytes of static random access memory (RAM) is provided by eight 8-bit wide memory devices. Additional input/output (I/O) interfaces are provided by a CRT alphanumeric controller card, a graphics controller card which permits graphics output to the CRT, a printer interface card, the serial communication card and a clock/calendar card providing time of day information for data stamping.

2. Power supply module for supplying ±15 VDC and +5 VDC from a 115 VAC, 60 Hz primary power source. The +5 VDC supply contains overvoltage and overload protection circuitry to safeguard the computer card cage population. An auxiliary 3 A switched AC outlet is located on the rear panel.

3. Keyboard module supporting an 89-key keyboard generating 7-bit ASCII character codes. The 89 keys are divided into 17 user definable keys, seven numeric keypad keys and 65 keyboard keys.

4. Display module consisting of a 30 cm (12 in) black and white CRT supporting 24 lines of 80 characters each with half intensity, reverse video and blanking attributes.

5. A versatile enclosure that serves to mount all the above components with provisions for back panel I/O interface connectors mounting. Provision also exists for two 13.3 cm (5.25 in) mass storage devices (one hard disk and one floppy disk).

The PDU maintenance is to the level of the five major assemblies as defined above. The projected maintenance method consists of identifying and replacing the assembly. A minimum of tools and no soldering is required. The computer card cage assembly is maintained to the card level.

User Interfaces

The PDU contains two hardware oriented user interfaces. These user interfaces are the keyboard module interface and the CRT module interface.

TABLE 5 PDU STD PRINTED CIRCUIT CARD LIST

No.	Description	Comment
1	Central Processing Unit (CPU)	16-Bit Architecture
2	EPROM Memory	64K ROM
3	RAM Memory	64K Static RAM
4	Clock	Date/Time Reference for Data Stamping
5	CRT Controller	Alphanumeric Character Generator
6	Graphics Controller	Permits Creation of Schematics on Cathode Ray Tube (CRT)
7	Serial Communication	Standard RS-232C Interfaces to Compatible Devices
8	Printer Interface	Standard Parallel Output to Printer

The PDU contains a keyboard module to serve as a user data and control input device. The keyboard module supports an 89-key keyboard generating seven bit ASCII character codes. The keyboard is housed separately and is removable from the PDU enclosure. Its cable connects to the PDU back panel. Internally, the keyboard character codes are made available to the computer card cage through a port of the parallel interface card.

A CRT module serves as the primary user output device. The CRT module consists of a 30 cm (12 in) black and white CRT. The CRT interfaces to a CRT alphanumeric controller card by a CRT interface card. The CRT interface card contains buffer amplifiers for the CRT control signals, provide half intensity and video blanking display attributes and the interface for point plot graphics capability. The CRT interface supports a point plot graphics card yielding a resolution 640 x 480 pixels. The alphanumeric controller card supports 24 lines of 80 characters each with reverse video and character blanking. The character generator supports 128 characters, upper/lower case alphanumeric and graphic characters. The alphanumeric card resides in the PDU computer cage and interfaces to the PDU application software via a 4K by 8 bit address space. The display memory is configured as 1920 x 8 bit RAM and can be written in the same way as any RAM located in the PDU. Each byte of the display memory is mapped into a unique position on the CRT screen.

Communication Interface

The PDU contains an interface port for communicating with the Series 200 C/M I computer. The nature of this interface is the RS-232C communications standard. Messages are divided into blocks and communicated across the link to the Series 200 C/M I. A PDU provision to provide an interface to the Series 100 Data Acquisition and Reduction System (DARS) is incorporated. This interface meshes with the DARS in the same manner as the Series 100. A PDU provision for a RS-232C port for a modem interface is also included. This port enables off-site computer terminal communications over phone lines via modems.

The PDU has clock/calendar time capability. This capability makes time-of-day and calendar information available for display and hard copy. To implement this capability, a clock/calendar time card, time setting circuitry and a software handler is required and included.

Integration of the PDU with an ECLSS subsystem controller is shown in Figure 6. A single 25 conductor cable connects the PDU with the subsystem controller.

Software Design

The PDU software is organized into four major software groups. These groups and supporting modules and routines are illustrated in Figure 7. A multitasking executive integrates these software groups into the PDU software package. The four major groups of software are: the Executive Group, the Communications Group, the User Interface Group and the Translator Group. Each is described below.

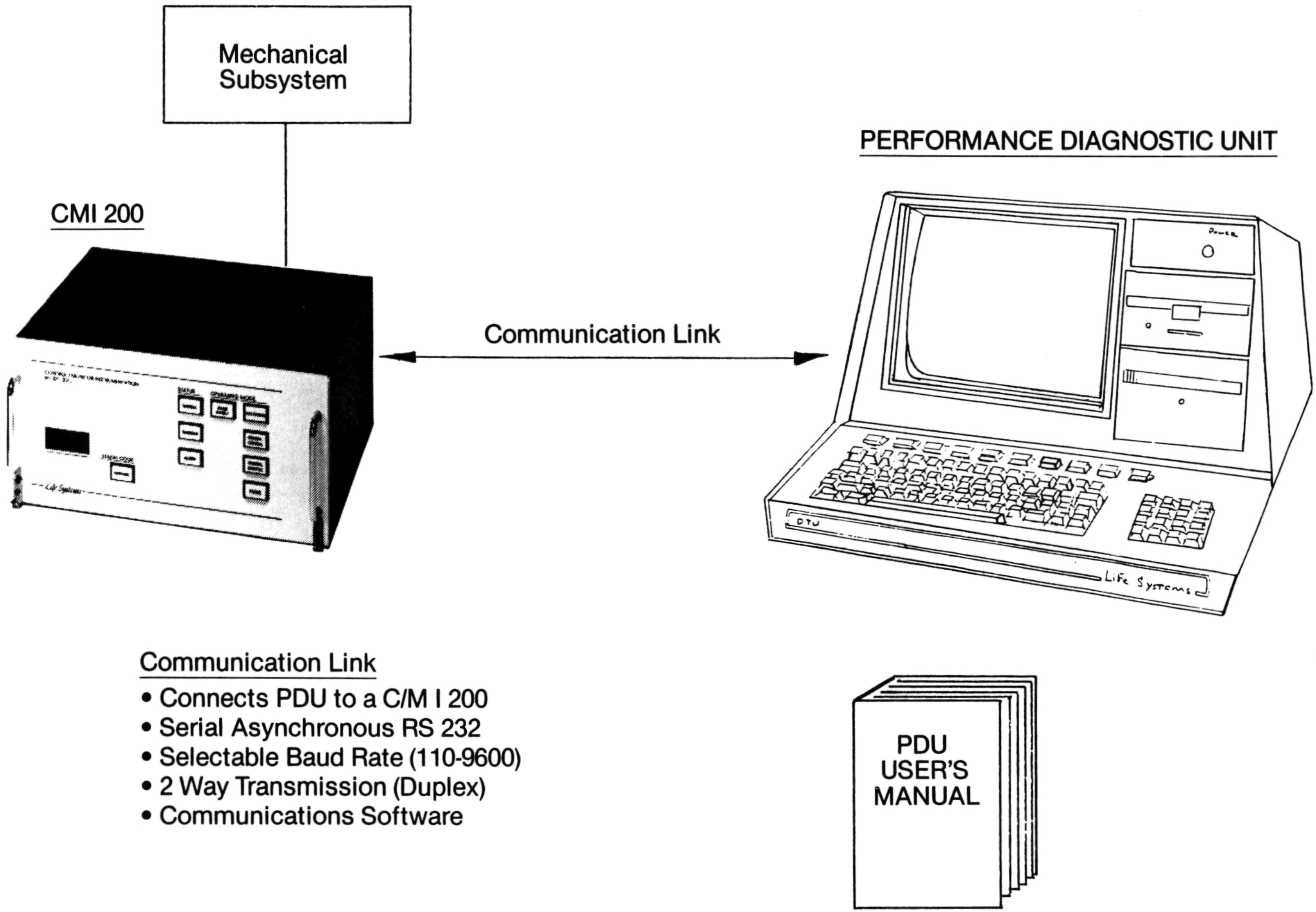
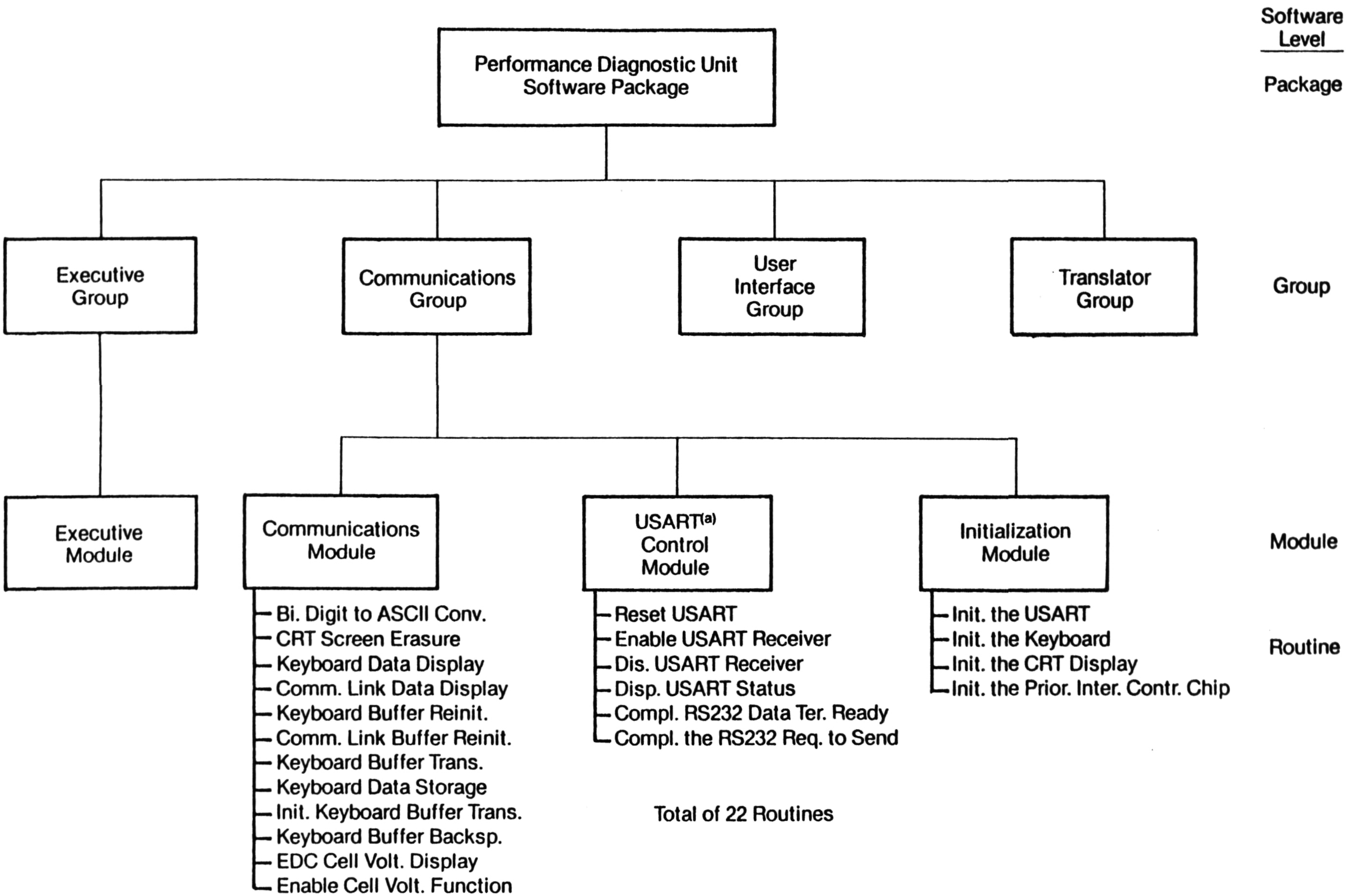


FIGURE 6 PERFORMANCE DIAGNOSTIC UNIT SYSTEM INTEGRATION



(a) Universal Synchronous Asynchronous Receiver Transmitter (USART) Chip.

FIGURE 7 PDU SOFTWARE PACKAGE

Executive Group

The Executive Group is a real-time multitasking operating system. Its message exchange features are utilized to provide intermodule interface, communications and task synchronization. The multitasking capabilities are utilized to provide a structured software architecture and to manage concurrent activities such as interrupt processing. The application software interfaces to the operating system through subroutine calls.

Communications Group

The Communications Group maintains the interface to the Series 200 C/M I microcomputer. It supports transmission and reception of data information and control information from the C/M I. The communications modules build the messages and manages their transmission out onto the communications link. It also accepts and deciphers messages sent from the C/M I computer.

User Interface Group

The User Interface Group provides the menu driven user friendly interface. It also maintains the keyboard, CRT and line printer interfaces. It accepts user requests, validates and interprets these requests, and passes these requests to the Translator Group. The Translator Group converts these validated requests into a series of local or PDU implemented messages to be sent to the C/M I computer. These messages identify the type of message (control or data request type) and contain any required data.

Basic Description and Function. The User Interface Group consists of three major groups of software: the keyboard module, the token processor, and the command recognizer. An ASCII buffer serves as the interface. When a full command line has been entered into the ASCII buffer by the keyboard module, the buffer is turned over to the User Interface Group. First, to operate upon the buffer is the token processor. It classifies the ASCII codes into type and value, parses the string into words called tokens and then attempts to identify the tokens by comparison to the known word lists. If the word is a numeric data value, the string is converted into its representative binary equivalent. Identified tokens are entered into a token buffer. Any numeric data is entered into a data buffer. The numeric data is stored in floating point real format. Once the input command string has been parsed into tokens, the command recognizer will attempt to identify the requested command. The successful identification yields a data communication request (to be sent to the Communications Group), a response message and a selected display format. If communication to the C/M I is required, the appropriate communication key is sent to the Communications Group. After the communication is performed, the Communications Group returns control to the command recognizer. The command recognizer then implements the requested command. If the command requests a display of data, control is transferred to the Display Group, otherwise control returns to the keyboard input module.

Command Classes. Valid commands are partitioned into five command classes. These are:

1. Class A - Subsystem Generic Commands

   A group of commands common to all Series 200 C/M I subsystems.

2. Class B - PDU Configuration Commands

   A group of command providing selection of PDU options.

3. Class C - Subsystem Specific Commands

   A group of commands specific to a particular subsystem. The operator shall select the subsystem of interest.

4. Class D - Diagnostic Functions

   A group of commands, specific to a subsystem, that provides diagnostic capability.

5. Class E - Subsystem I/O Complement

   A list of the sensors and actuators which identify the supported subsystem. The operator shall select the subsystem of interest.

A summary of the supported commands is contained in Table 6.

Command Expansion. The User Interface Group is designed to allow easy enhancement of the user interface with new commands. This is accomplished by dividing the commands up into component words, and adding these words to the appropriate word list. The next step expands the software of the appropriate command class to recognize the new command. Then finally, a procedure implements the new command's intended function.

Translator Group

The basic function of the Translator Group is to manage the CRT display, particularly the display of C/M I data in engineering units. The C/M I system mode and status display area is updated whenever a message is transmitted or received from the C/M I. Time and date are tracked internally and are updated at least twice a second. The requested data display area features windowing capability. The capacity of this capability is selectable. As data from the C/M I arrives for display, older data is pushed back in memory to make room for the new data. Special function keys allow for window positioning anywhere within the array of C/M I received data. Additionally, the Translator Group manages an interface to a line printer.

A selected format is chosen by the User Interface Group and sent to the Translator Group. A message builder module accepts the format, and determines the sources of the data. A line of display is built by converting the data into ASCII characters and adding the appropriate label and engineering unit

TABLE 6 PDU COMMAND SUMMARY

Commands	Receive and Display Data[a]	Send[a] Data	Control Command	Receive and Display Status	Comments
Generic C/M I					
Actuator Data	✓	-	-	-	Engineering Units
Override Actuator Data	✓	✓	-	-	Engineering Units
Request Actuator Override	-	-	Enable, Disable	✓	All, Individually
Sensor Data	✓	-	-	-	Engineering Units
Override Sensor Data	✓	✓	-	-	Engineering Units
Request Sensor Override	-	-	Enable, Disable	✓	All, Individually
Request Menu Command	-	-	-	-	Lists Supported Commands
Fault Detection Setpoints	✓	✓	-	-	Mode and Status
System Timers	✓	-	-	-	-
Sensor Status	✓	-	-	-	Alarm, Warning, Normal
Fault Detection Override	-	-	Enable, Disable	✓	All
Sensor State	✓	-	-	-	All
Sensor Tolerance	✓	✓	-	-	Engineering Units
Specific C/M I					
C/M I Signature	✓	-	-	-	Subsystem Type, Sensors, Actuators
CCA[b] Control Loop Parameters	✓	✓	-	-	Engineering Units
FCA[b] Control Loop Parameters	✓	✓	-	-	Engineering Units
Current Loop Parameters	✓	✓	-	-	Engineering Units
RH Loop Parameters	✓	✓	-	-	Engineering Units
RH Profile	✓	-	-	-	Engineering Units
RH Loop Control	-	-	✓	-	-

continued-

(a) Perspective of PDU, i.e., PDU Receiving Displaying and Sending Data.
(b) CCA = Coolant Control Assembly.
FCA = Fluids Control Assembly.

Table 6 - continued

Commands	Receive and Display Data[a]	Send Data	Control Command	Receive and Display Status	Comments
Specific C/M I - continued					
CCA Loop Position	-	-	✓	-	+/- TBS Degrees
FCA Position	-	-	✓	-	Open/Closed/Purge

Commands	Description
PDU Configuration	
Every <Time Value> <Time Value>	Specifies a delta difference from current time, range 5 sec to 24 hr.
Print <Actuator/Sensor ID>	Prints the value of requested sensor or actuator, based on recent value.
and Print <Actuator/Sensor ID>	Connects with display command. Allows printing of displayed data.
TIME - hr/min/sec	Sets the PDU time.
DATE = yr/mon/day	Sets the PDU date.
DEFINE <KEY> = "ASCII STRING"	Equates KEY to an ASCII STRING.
HELLO	Sends ACKNOWLEDGE message to C/M I (Response Message includes STATUS, Mode Transitions).
Print Screen	Prints a copy of the CRT screen.
CLEAR	Clears display screen.

continued-

Table 6 - continued

Command	Function	Description
Diagnostic Functions		
Verify CCA	Exercises CCA Diverter Valve	Displays Status (GO, NOGO).
	Exercises CCA Pump	Displays Status (GO, NOGO).
Verify FCA	Exercises FCA	Displays Status.
Verify Current	Ramps Current and Verifies	Displays Status.
Independent Fault Detection	Compares Data with Setpoints	Provides display of subsystem sensors, scans for fault occurrence, highlights warning by reverse video, highlights alarm by blinking (indicates previous high/low values).

declarations. This line of ASCII characters is then sent either to the data display module and/or the printer interface. The message builder repeats and builds another line of ASCII characters, until all the required data is translated. The PDU has the capacity to hold an amount of data equivalent to two CRT screens. This capacity is selectable. This is accomplished by backing up the CRT screen memory with an equivalent amount of system memory. Coupled with provisions to scroll data off and on the CRT display, the CRT can be viewed as a data window that is moved up and down through a file of processed data.

Fabricated PDU

Figure 8 shows the fabricated PDU, while Figure 9 illustrates the eight STD computer bus cards used. All hardware parts were purchased off-the-shelf and final assembled. Some minor interconnecting cabling was fabricated in-house.

The software was written and tested using the CS-1 EDC subsystem with its Model 220 C/M I as the target subsystem. Figure 10 shows the subsystem schematic which normally appears on the screen. To see all data in a tabular format, a screen such as that shown in Figure 11 can be brought to the screen. Table 7 summarizes the PDU commands presently available.

GENERIC SIGNAL CONDITIONING

The development of generic sensor S/C concepts and hardware designs is discussed in this section of the Final Report. It covers the state-of-the-art in S/C, design requirements and design details including a description of the hardware fabricated under a separate Life Systems supported program. A discussion of key design and operational issues are also presented.

State-of-the-Art Signal Conditioning

Signal conditioning in a C/M I environment is required to interface sensors of physical phenomena (e.g., temperature, pressure) with an analog or digital-based intelligence. Prior techniques and present day advances in S/C approaches and hardware are discussed in the following.

Past Techniques

Life Systems' development of generic sensor S/C concepts and hardware was prompted from several considerations. Traditionally, as shown in Figure 12, the prior techniques required dedicated S/C card(s) for each sensor. The S/C provides amplification, filtering, isolation, attenuation, impedance matching, gain or whatever conditioning is required. The purpose is to develop a standardized (typically 0 to 5 VDC) signal to the multiplexer and analog to digital (A/D) converter of the computer over the sensor range of interest. For example, a S/C output of 0 to 5 VDC might correspond to 277 to 305 K (40 to 90 F) for a temperature sensor. This approach to S/C required a separate circuit or card, even though multiple circuits of the same type could be

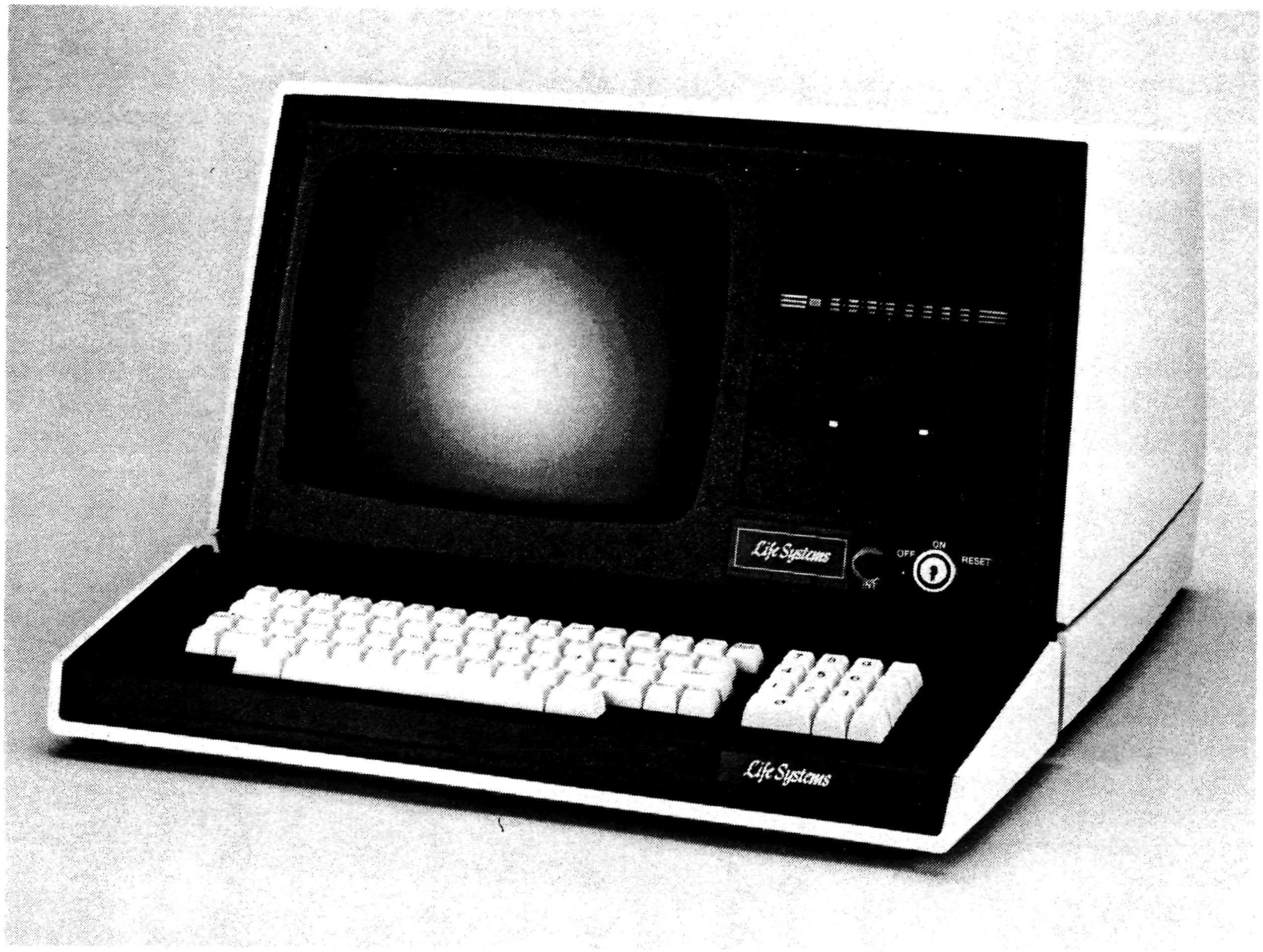


FIGURE 8 PERFORMANCE DIAGNOSTIC UNIT - ASSEMBLED

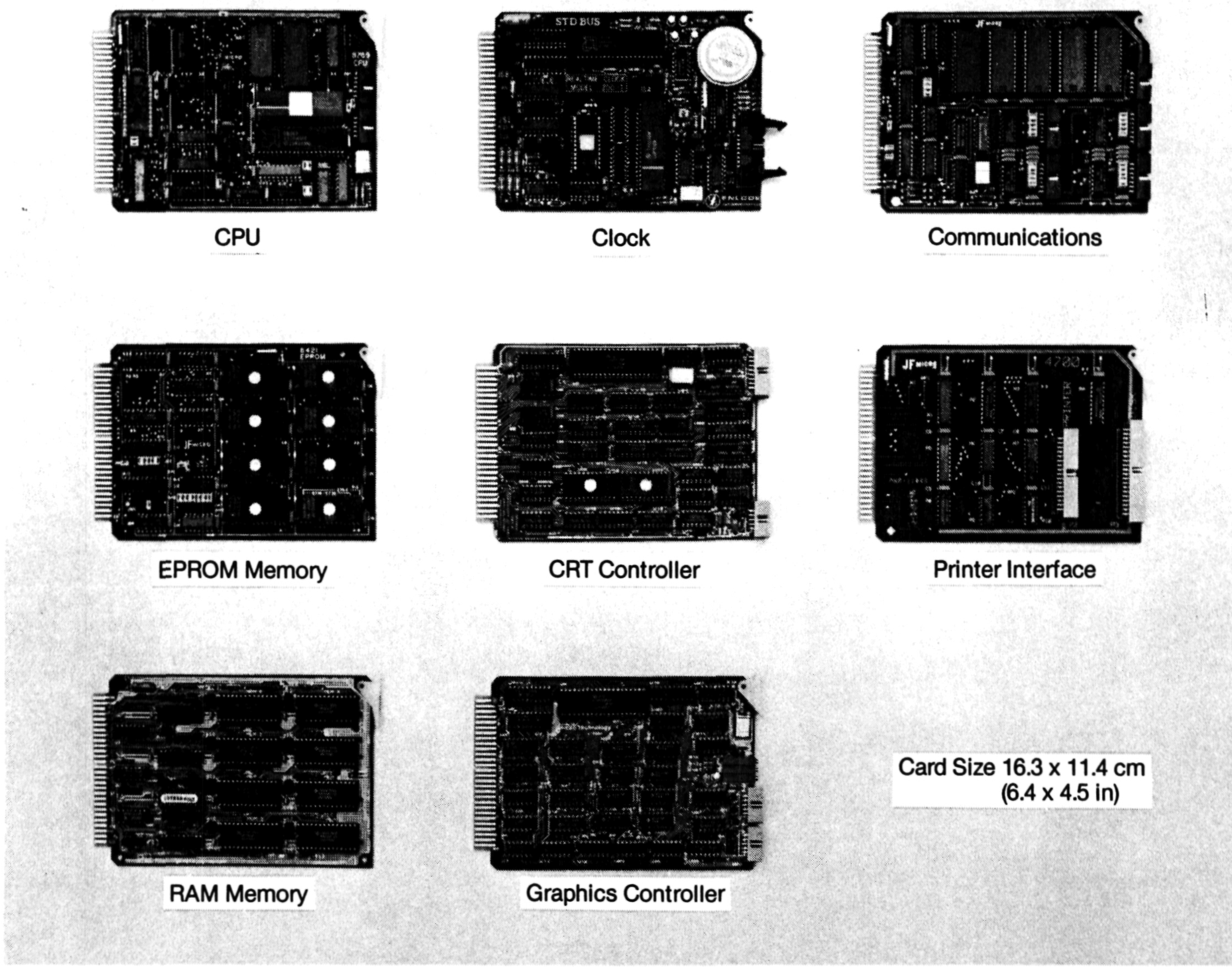


FIGURE 9 PERFORMANCE DIAGNOSTIC UNIT PRINTED CIRCUIT CARDS

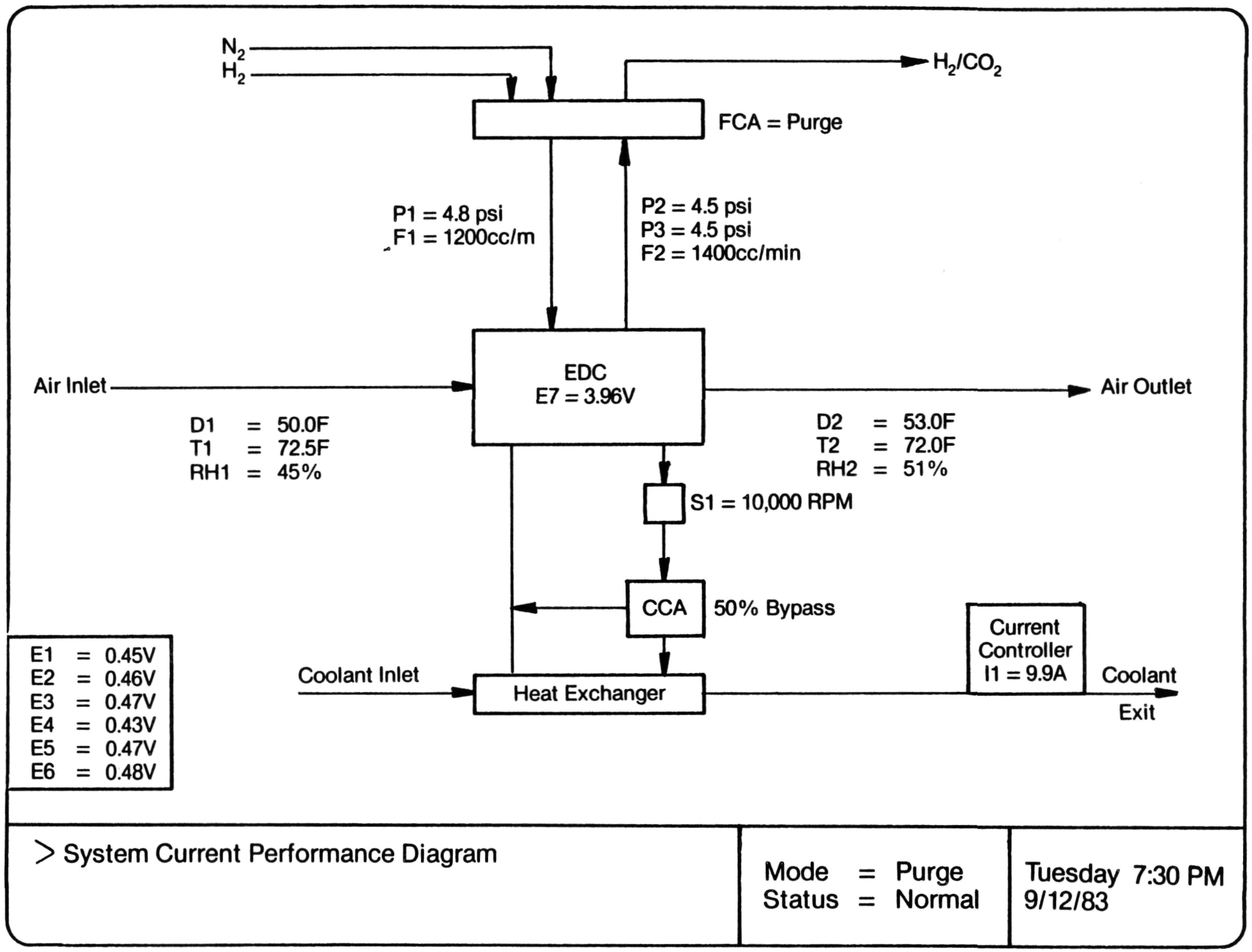


FIGURE 10 SUBSYSTEM SCHEMATIC

CMI 220 Data

F1	=	1300 cc/min	T11	=	69.0F HW
F2	=	1320 cc/min	T12	=	68.5F HW
P1	=	2.3 psi	T13	=	69.5F HW
P2	=	2.4 psi	T21	=	78.0F
P3	=	2.5 psi	T23	=	77.5F
E1	=	0.65V	D11	=	55.0F
E2	=	0.66V	D12	=	55.5F
E3	=	0.67V	D13	=	56.5F
E4	=	0.63V	D21	=	57.0F
E5	=	0.67V	D22	=	57.0F
E6	=	0.68V	D23	=	57.0F
E7	=	3.96V	RH1	=	65.0%
I1	=	9.8 Amps	RH2	=	65.3%
S1	=	9.9K RPM			
W1	=	Isolate (50%)			
W2	=	Thrupass (85%)			

> Sensors Every 10 Sec. and Print

Mode = Purge
Status = Warning

Tuesday 7:39 PM
9/12/83

FIGURE 11 EXAMPLE OF SENSOR DATA TABLE

ABLE 7 PDU COMMANDS

CLASS A: C/M I GENERIC COMMANDS

Command Description	Command Format
Display Actuator Data	(Actuator ID)
Override Actuator Data	(Actuator ID) = Value
Request Actuator Override	(Actuator ID) Override = On/Off
Display Sensor Data	(Sensor ID)
Override Sensor Data	(Sensor ID) = Value
Request Sensor Override	(Sensor ID) Override = On/Off
Display/Override Setpoints	(Sensor ID) (Mode) (Setpoint) = On/Off/Value
Display System Timers	(Z Timer ID)
Display Sensor Status	(Sensor ID) Status
Display Sensor State	(Sensor ID) State
Display Sensor Tolerance	(Sensor ID) Tolerance
Establish C/M I Link	Hello

CLASS B: PDU CONFIGURATION COMMANDS

Command Description	Command Format
Set Time	Time = Hr/Min/Sec
Set Date	Date = Mon/Day/Yr
Define Key	Define (Key ID) = "ASCII String"
Print Data	Print (Sensor ID, Actuator ID, Z Timer ID)
Display and Print Data	Display (ID) and Print (ID)
Repeat Command	(Command) Every (Value)
Display Menus	Help
Print Screen	Print a Copy of the CRT Screen

CLASS C: C/M I 220 SPECIFIC COMMANDS[(a)]

Command Description	Command Format
Request CCA Position	CCA = Bypass/Initial/Thrupass
Request CCA Delta Position	CCA = +/- Value
Request FCA Position	FCA = Closed/Purge/Open
Enable/Disable RH Loop	RH = Enable/Disable
Request RH Profile	RH Values
Display CCA Parameters	CCA
Change CCA Parameters	CCA Rate = Value
Display FCA Parameters	FCA
Change FCA Parameters	FCA Rate = Value

continued-

(a) A unique list is developed for each C/M I. The commands shown are for the C/M I 220 of the CS-1 Subsystem.

?IC COMMANDS - continued

Command Description	Command Format
Display Current Parameters	CUR
Change Current Parameters	CUR Rate = Value; CUR Setpoint
Display RH Parameters	RH
Change RH Parameters	RH Rate = Value
	RH Gain = Value
	RH Offset = Value

CLASS D: DIAGNOSTIC FUNCTIONS FOR CS-1

Command Description	Command Format
Verify CCA Div. Valve	Verify CCA
Verify FCA Function	Verify FCA
Verify Current Control	Verify CUR
Verify CCA Pump	Verify Pump
Perform Independent F.D.	Fault Det = Enable/Disable

CLASS E: SUBSYSTEM I/O COMPLEMENT FOR CS-1

Sensor List		Actuator List	
C11 - C13	Combustible Gas	XI1	EDCM Current On/Off
F1	Inlet Flow	M1	Coolant Pump On/Off
F2	Outlet Flow	V1	CCA
P1	Inlet Pressure	V2	FCA
P2 P3	Outlet Pressure	X12	EDCM Current Setpoint
E1 - E6	EDCM Cell Voltages	Z1	Total Operating Time
E7	EDCM Module Voltage	Z2	Time Since Shutdown
I1	Module Current	Z3	Time of Shutdown
T11 - T13	Inlet Temperature	Z4	Time in Normal Shuttle
T21 - T23	Outlet Temperature	Z5	Time in Shutdown
D11 - D13	Inlet Dew Points	Z6	Time in Purge
D21 - D23	Outlet Dew Points	Z7	Time in Normal Central
W1	FCA Position	Z8	Time on EDCM
W2	CCA Position	Z9	Time on Pump
S1	CCA Pump Speed	Z10	Time Not in Shutdown
RH1	Inlet RH		
RH2	Outlet RH		

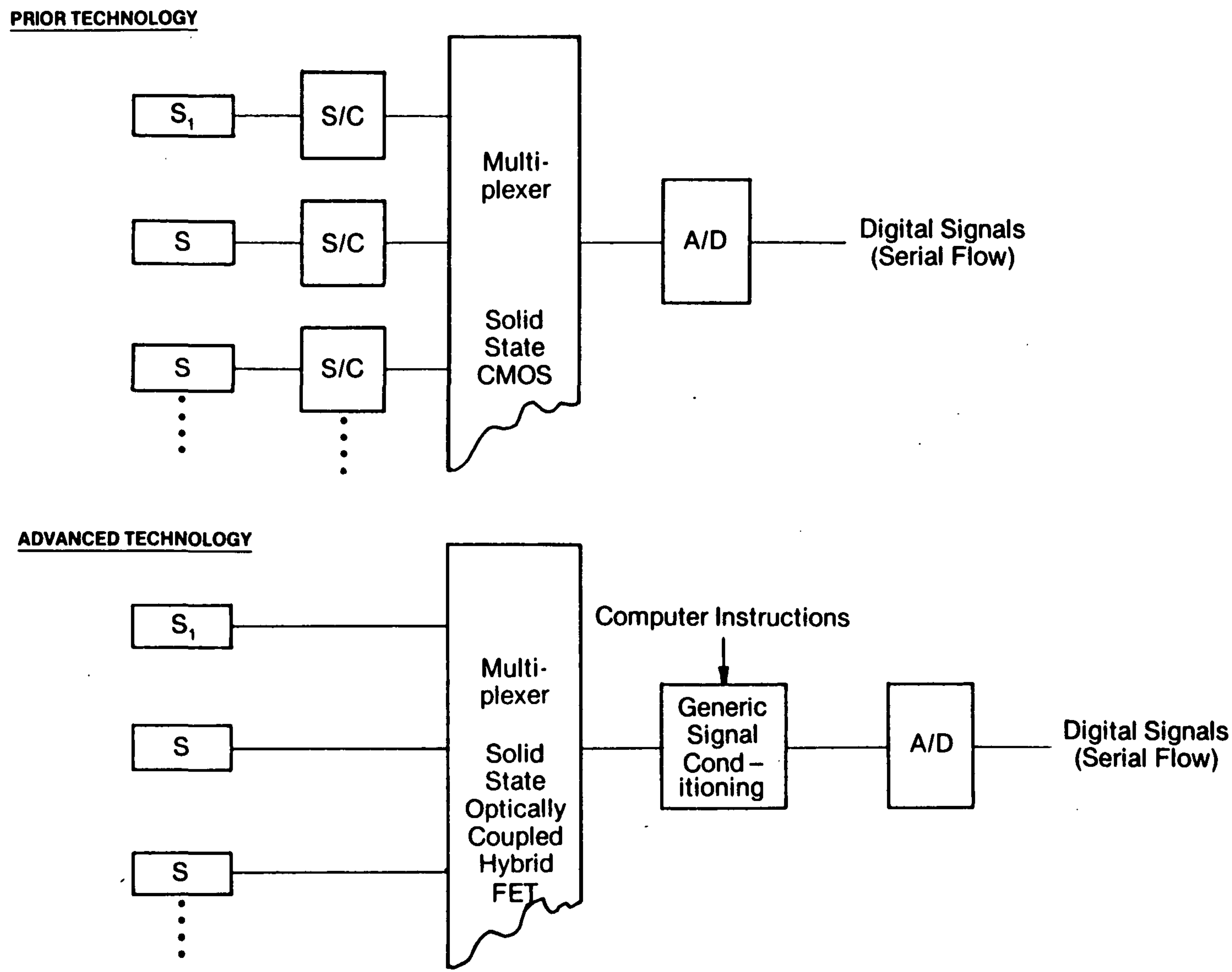


FIGURE 12 COMPARISON OF SENSOR SIGNAL CONDITIONING APPROACHES

e Systems has developed an inventory of over 15 cards for different types of sensors (see Table 8). Also, calibration for each sensor S/C was on the card itself and adjustment to account for differences in circuit components and sensors was made using potentiometers. This has two disadvantages: (1) the need to make the adjustments during a calibration procedure and (2) the need to recalibrate due to sensor changes or circuit drifts.

Another disadvantage of the prior technology is the requirement for a large wire bundle between the sensors and the S/C and then from the S/C to the multiplexer and A/D. If the S/C, multiplexing and A/D hardware is located in the controller enclosure and the controller is located remotely then a large number of wires of considerable length is required. This is particularly true for those systems having a large number of sensors. As an example, a few years ago Life Systems developed an integrated Air Revitalization System (ARS) using the prior S/C technology and a minicomputer-based C/M I. There were over 100 sensors in the system. Including commons and shields, there were 541 individual wires entering the C/M I for sensors only. If actuator, Test Support Accessories (TSA) and power wires are included a total of 843 wires were needed. The diameter of the wire bundle was over 15 cm (6 in).

<u>Current Techniques</u>

As part of Life Systems' continuing goal to reduce the size of its ECLSS S/C and make it more generic (i.e., applicable to more sensors using the same hardware) a concept shown in the second portion of Figure 12 was designed. Here the time-division multiplexing of the sensor signals takes place prior to S/C and A/D. The sequence of S/C and multiplexing has been reversed. One of the reasons that this was not practical in the past is that multiplexers were generally large, i.e., took large amounts of area on a printed circuit board. Recent technology (post-1983) advancement has permitted electrically isolated, solid-state, multiplex switches to be made in very small integrated circuit packages. Therefore, it is feasible to have 16 channels of electrically isolated multiplexing on the same circuit card size as our standard S/C. Generic S/C under this approach uses a universal, programmable gain instrumentation amplifier. The computer sets the zero offset and gain for each sensor as it comes into the amplifier in sequence. The output of the amplifier then is directed to the A/D for conversion. At any given time the computer knows what sensor is being scanned and what its scale factors are to give the right conversion to engineering units.

The overall architecture for a controller using generic sensor S/C is shown in Figure 13. A significant advantage of the generic sensor S/C approach is that the required electronic circuits can be located with the mechanical assembly and the wire bundle going between it and the remotely located microcomputer assembly is very small - 12 wires total.

<u>Analog Electronics</u>

Compared to digital technology, progress in analog electronics has been evolutionary rather than revolutionary. Analog technology undergoes continuing refinement of processes and techniques, rather than abrupt changes. For

IFE SYSTEMS' COMMON PC CARDS
FOR SENSOR SIGNAL CONDITIONING

Sensor Type	Sensor/ Card	Comments
Cell Voltage	10	One Output; Inputs Multiplexed
Combustible Gas (Thermistor)	2.5[(a)]	
Conductivity (Liquid)	2	
Current	10	
Dew Point	2	
Flow (Thermistor)	2.5[(a)]	
Isolation Amplifier	2	General Purpose Amplifier; Used for Cell Voltage
Level (Liquid)	1	
LVDT	1	
pH	2	
Potentiometer	10	Valve Position Indicator
Pressure	3	Strain Gauge
Speed	3	Optical or Magnetic Pickup
Temperature - RTD	5	
Temperature - Thermistor	5	
Temperature - Thermocouple	2	Does Not Include Cold Junction Reference

(a) Two thermistors per functional sensor (i.e., 5 thermistor circuits/cards).

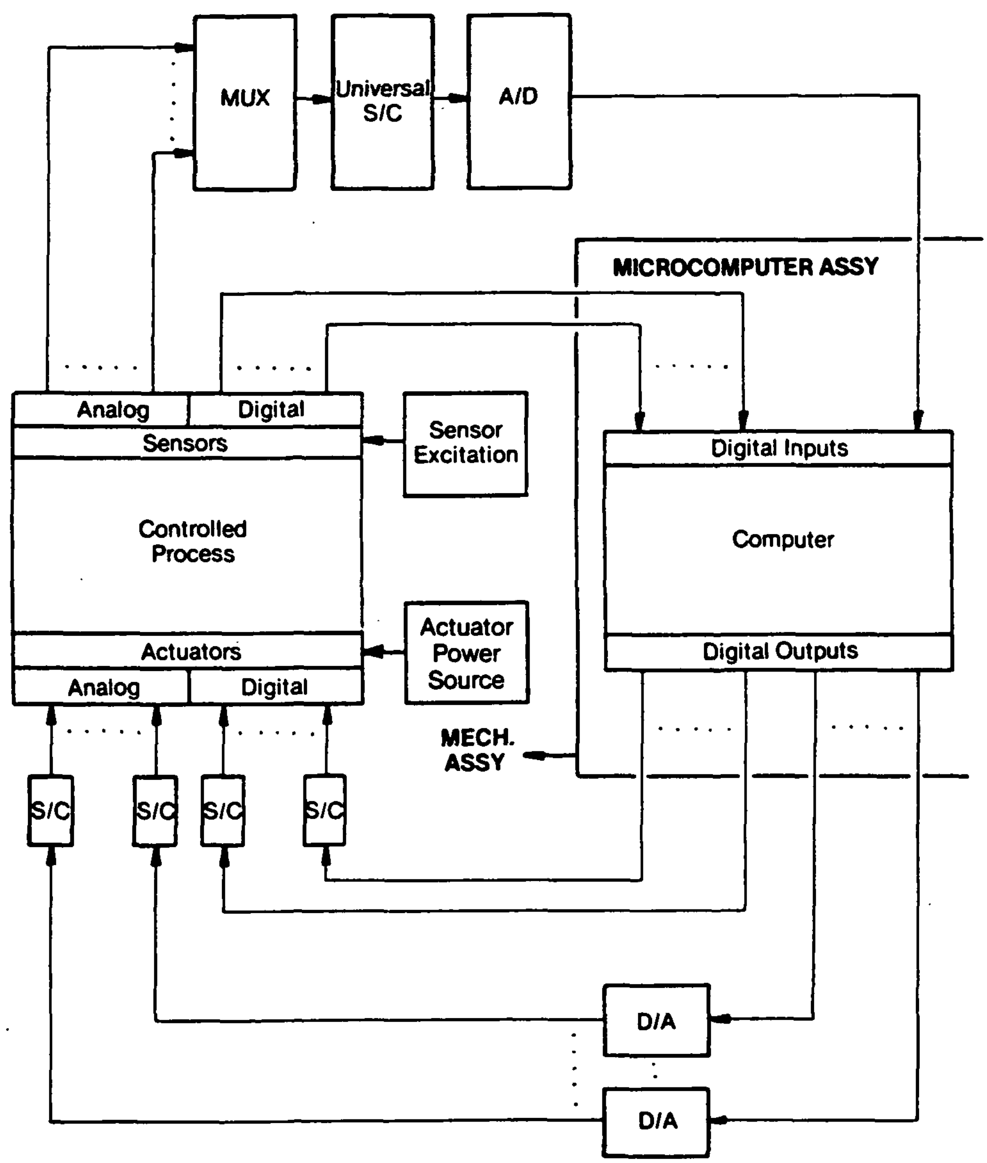


FIGURE 13 ARCHITECTURE FOR CONTROLLER USING GENERIC SENSOR SIGNAL CONDITIONING

s remain the key building block in analog systems as they were 25 years ago. Yet their performance/cost and performance/size ratios have improved orders of magnitude. This leisurely advancement of analog electronics will probably continue even as alternative technologies step in and obsolete it. Advancements in both sensor and microprocessor technologies are already encroaching on analog territory. Table 9 summarizes the state-of-the-art in analog S/C components.

Because of the dramatic drops in cost of digital memory, many analog functions are being replaced with equivalent software. Examples include:

1. Linear and non-linear filtering
2. Automatic error correction (e.g., gain and zero adjustment)
3. Sensor calibration
4. Linearization and units conversion
5. Fault detection

The benefits of software implemented functions is as follows:

1. Compared to analog hardware eliminated, less space is required for equivalent firmware[a] (even if additional memory integrated circuits (ICs) are required).

2. Lower material cost (at the price of a higher software development cost).

3. Stable transfer functions - software algorithms do not drift with time and temperature, and are repeatable unit-to-unit. Not so with analog hardware.

4. Periodic checking of remaining analog hardware and automatic correction of errors (both initial and time/temperature induced).

5. No manual calibration adjustments - with potentiometers there is risk of initial mis-adjustment, and shifts with shock and vibration.

Trade-off of an analog versus digital approach for S/C is based on several factors. Evaluation and trade-off criteria are given in Table 10.

<u>Smart Sensors</u>

Progress is not as rapid on the sensor front, though increasing numbers of solid-state sensors are becoming commercially available. By incorporating front-end S/C into the sensor (often a single chip contains both sensor and its S/C), high-level outputs are provided that interface directly to an A/D converter. Though still under development, there will eventually be sensors that include both S/C and an A/D. These sensors will connect directly to computers. Progress toward this end is delayed by the lack of a digital

(a) Firmware is hardware used to contain software.

TABLE 9 INDUSTRY STATE-OF-THE-ART IN ANALOG S/C COMPONNETS

No.	Category	Type	Manufacturer/Part No.	Characteristic/Comment
1	Solid-State Sensors	Temperature	Analog Devices AD590	Linear output current proportional to absolute temperature; 1μA/K over 218 to 423 K (-65 to 300 F) range ±0.5 K (±0.9 F) calibration accuracy
			National Semi LM35	218 to 423 K (-65 to 300 F) range Voltage output; Kelvin scaling
		Pressure	Sensym	Absolute, gauge and differential configurations; High-level output (10 V output swing between input limits)
		Magnetic	Microswitch	Hall-effect proximity and current sensors
2	Operational Amplifiers	Low Drift	Intersil ICL7650	5 μV initial offset, 0.05 μV/K (0.03 V/F) Technology - CMOS chopper stabilized monolithic
		Low Bias (Electrometer)	Analog Device AD515	75 fA input current. Technology: FET input bipolar monolithic
		Low Power	Intersil ICL76XX	Power: 10 μA at ± 0.5 V Technology: Linear CMOS monolithic
		Low Noise	Precision Monolithics OP-27	Noise: 80 nVpp at 0.1 Hz to 10 Hz, 3 nV/ √Hz at 1 KHz Technology: Bipolar
		Wide Bandwidth and High Speed	Harris HA-2539	Gain-Bandwidth Product: 600 MHz Power Requirements: 25 mA at ±15 V Technology: Dielectrically isolated bipolar

continued-

Table 9 - continued

No.	Category	Type	Manufacturer/Part No.	Characteristic/Comment
2	Operational Amplifiers - continued			
		Power	Burr-Brown OPA-501	Max. Supply Voltage: ±40 V Peak Output Current: ±10 A Peak Output Power: 260 W Technology: Hybrid bipolar
3	Operational Amplifiers	Hybrid	Burr-Brown 3606	Digitally Programmed Gain 11 Binary Gains (1, 2, 4, ..., 1,024) Package: 4.47 x 2.95 x 0.58 cm (1.76 x 1.16 x 0.23 in) Technology: Laser trimmed bipolar
		Monolithic	Analog Devices AD525	Hardware Controlled Gain 4 Decade Gains (1, 10, 100, 1,000) 16-pin DIP Technology: Laser trimmed bipolar
4	Isolation Amplifiers	Optical	Burr-Brown 3650	2,000 V isolation 15 kHz bandwidth Package: 4.47 x 2.95 x 0.58 cm (1.76 x 1.16 x 0.23 in)
		Magnetic	Analog Devices AD294	3,500 V isolation 2.5 kHz bandwidth Package: 6.70 x 2.18 x 0.91 cm (2.64 x 0.86 x 0.36 in)
5	Transducer Dedicated S/C	LVDT	Signetic NE5520	Monolithic S/C including excitation, synchronous demodulator and output amplifier; ±5 V output typical
		Thermocouple	Analog Devices AD594	Monolithic instrumentation amplifier and cold-junction compensator Scaled output 10 mV/K (5 mV/F)

continued-

Table 9 - continued

No.	Category	Type	Manufacturer/Part No.	Characteristic/Comment
6	Voltage References	Hybrid	Burr-Brown REF101	+10.000 ± 0.005 V 1 ppm/K (0.5 ppm/F) temperature coefficient Quescient current ≤6 mA
		Monolithic	National Semi LM199	Temperature regulated subsurface zener diode +6.95 ± 0.15 V 0.5 ppm/K (0.3 ppm/F) temperature coefficient 14 mA temperature stabilizer current (200 mA turn-on surge)
7	Precision Resistors	Bulk Alloy	Vishay "H" Series	±0.001% initial tolerance <1 ppm/K (<0.5 ppm/F) temperature coefficient ±0.002% 'load-life'
		Thick Film	Caddock "Tetrinox" Film	±0.005% initial tolerance <5 ppm/K (3 ppm/F) temperature coefficient ±0.05% 'load-life'
8	Multiplexers	Electro-mechanical	Reed Relays	Speed: 1-3 msec Leakage (off) 10^{10} ohms Resistance (on) 10 mohms Power 125 mW Off-Voltage (max) 250 V
		Solid State	CMOS Switches	Speed 3 μsec Leakage (off) 10^{11} ohms Resistance (on) 1,000 ohms Power <1 mW Off-Voltage (max) 35 V
			Opto-Coupled Power FETs (Hybrid)	Speed 500 μsec Leakage (off) 10^{10} ohms Resistance (on) 750 ohms Power 10 mW Off-Voltage (max) 250 V

continued-

Table 9 - continued

No.	Category	Type	Manufacturer/Part No.	Characteristic/Comment	
9	A/D Converters	Monolithic	Analog Devices AD5240	Resolution	12 bits
				Speed	5 μsec
				Power	775 mW
				Technology	Bipolar
			Intersil ICL7115	Resolution	14 bits
				Speed	50 μsec
				Technology	CMOS
		Hybrid	Burr-Brown ADC803	Resolution	12 bits
				Speed	1-5 μsec
				Power	2-4 W
			Burr-Brown ADC76	Resolution	16 bits
				Speed	15 μsec
				Power	1-6 W
		Modular	Analog Devices MOD-1205	Resolution	12 bits
				Speed	0.2 μsec
				Power	13 W
10	D/A Converters	Monolithic	Analog Devices AD7240	Resolution	12 bits
				Speed	550 μsec
				Power	30 mW
			Burr-Brown DAC 701	Resolution	16 bits
				Speed	8 μsec
				Power	790 mW

TABLE 10 SIGNAL CONDITIONING EVALUATION AND TRADE-OFF CRITERIA

1. Performance
   - Accuracy
   - Speed
   - Resolution

2. Size/Sensor Ratio
   - Dimensions (circuit card)
   - Volume (packaged S/C)
   - Weight

3. Power Requirements
   - Consumption
   - Heat Rejection

4. Reliability
   - Mean Time Between Failures (MTBF)
     - Number of components per sensor
     - Component Grades
       - Mil/Space/Hi-Rel
       - Industrial
       - Commercial
     - Use Environment
     - Electrical Stress
       - Normal Operation
       - Fault Conditions
     - MIL-HDBK-217D
       - Identification of failure rates. Defines resupply needs.

5. Fault Management
   - Fault Detection (Self-test capability)
   - Fault Isolation (Locate fault, and limit its impact on non-faulty equipment)
   - Fault Correction (Provide repair instructions or automatic fault healing)
   - Noise and RFI Rejection

6. Maintenance
   - Calibration
     - Initial
       - Number of adjustments required (e.g., offset, gain)
       - Calibration equipment required
     - Periodic
       - Recalibration interval
   - Repair
     - Service aids
       - Documentation
       - Built-in tests and instructions
     - Level of replacement of defective components (e.g., component, circuit board or subsystem

continued-

Table 10 - continued

7. Environmental Impact
    - Safety
        - Electrical, mechanical and chemical hazards
        - Fail safe operation
    - RFI output

8. Cost
    - Initial System
    - User Training
    - Maintenance

9. User Acceptability
    - Training
    - Complexity of operation
    - Reliability/Maintenance issues

10. Application Flexibility
    - Versatility. Ease of adapting instrumentation to variety of applications
    - Growth Potential. Ease of expanding systems to larger applications, and incorporating state-of-art enhancements in hardware/software
    - Software versus hardware programming

11. Interface Complexity
    - Number of electrical conductors and cables connecting S/C to sensors and controller.
    - Communication protocols
    - Burden on host
        - Memory
        - Speed

12. Technology Risk
    - 'Track record' of components and architecture

interface standard. Also, user familiarity with current sensors results in some resistance to accept the new sensors. Furthermore, present solid-state sensors are incompatible with many measurement extremes such as high temperature and corrosive media. Reliance on sensors of proven historical record is favored by system designers.

Design Requirements

In order to develop the generic S/C approach, a survey of representative ECLSS subsystems was made. Table 11 shows the controller requirements of several ECLSS subsystems and includes the number and types of the different sensors needed. The electrical characteristics of the sensors reveals that the majority of electrical measurements associated with the sensors are either direct current or direct voltage (see Table 12). Alternating current or voltage measurements are few in number.

These findings suggested the feasibility of a common S/C design able to accommodate the majority of sensors found in ECLSS hardware. Programmable gain (either hardwired or software set) would allow for signal magnitude variations between sensor types - from the extremes of millivolt thermocouple signals to several volt electrochemical module signals.

This common or generic S/C approach requires the development of four special cards which, when configured into a system, form all the sensor S/C required. These four are the following:

a. A multiplex card using optically coupled multiplexing switches for sensor selection.

b. A universal S/C card using a programmable gain instrumentation amplifier and an isolation amplifier for electrical isolation.

c. An A/D converter card to transform analog sensor information to digital data for computer processing.

d. A sensor excitation card which can be used to provide DC voltage and/or current drive to those sensors which require it.

The remainder of this section discusses the design of these four generic S/C cards.

Generic S/C Design - General

Computer Assisted S/C

Since the ECLSS C/M I is microprocessor (μP) based, it is logical to take full advantage of software to reduce the size and complexity of S/C hardware. Examples were given above of S/C functions (e.g., filtering, calibration, etc.) which can be implemented with software routines rather than analog hardware. These are further elaborated upon.

TABLE 11 CONTROLLER REQUIREMENTS OF SIX REPRESENTATIVE ECLSS SUBSYSTEMS

Characteristic	ECLSS Subsystems EDC	S-CRS	SFWES	VCDS	HFS	WQM
No. of Modes	5	5	9	5	6	45
No. of Operating Modes	4	4	8	4	5	34
No. of Mode Transitions (MT)	13	12	26	14	13	10
No. Prog., Allowable MT	9	8	18	10	8	7
No. Actuators	5	7	6	6	23	8
No. Sensors	40	21	34	15	18	10
Voltage Tab	25	-	9	1	-	-
Current Shunt	1	-	1	-	-	-
Calculated	2	-	-	-	-	-
RTD	4	-	-	-	-	-
Potentiometer	1	-	-	-	-	-
LVDT	1	-	-	-	-	-
Strain Gauge Bridge	3	4	9	2	5	-
Thermistor	2	6	3	2	7	4
Magnetic Pickup	1	1	-	3	-	-
Photodetector	-	-	-	-	-	-
Relay Contacts	-	4	1	4	-	2
Thermocouple	-	6	11	-	-	-
Conductance	-	-	-	1	1	1
Mag. Reed Switch	-	-	-	1	4	-
Ion-Selective Electode	-	-	-	1	1	3
Mass Spectrometer	-	-	-	-	-	-
No. of Control Def.	2	3	5	9	11	7
Powe, AC, W	48	35	484	301	669	550
Power, DC, W	-111[a]	0	996	85	0	0
Power, Total	-63[a]	35	1,480	115	669	550
Head Rej., W	231	332	580	115	669	550
Mode Trans. Sequences	49	37	35	20	35	22
No. PC Card List	22	22	23	21	20	21
No. Timers	10	10	12	15	9	9
No. Analog Inputs	48	32	54	10	25	18
No. Analog Outputs	4	-	2	1	-	1
No. Digital Inputs	8	12	6	14	6	4
No. Digital Outputs	19	6	12	10	15	14

(a) Generates DC power.

12 CHARACTERISTICS OF ECLSS SENSORS

Sensor	Excitation[a]	Primary Measurement[a]	Auxiliary Measurements[b]
Voltage Tab	-	DV	-
Shunt	-	DV	-
RTD	DC	DV	-
Potentiometer	DV	DV	-
LVDT	AV	AV	-
Strain Gauge Bridge	DV	DV	-
Thermistor	DC	DV	-
Magnetic Pickup	-	Frequency	-
Photodetector	-	DC	-
Relay Contacts	DV	DV	-
Thermocouple	DC (Cold Junction Sensor)	DV	DV (Cold Junction Sensor)
Conductance	AC	AV	-
Magnetic Reed Switch	DV	DV	-
Ion-Selective Electrode	DC (Temperature Sensor)	DV (High Impedance)	DV (Temperature Sensor)
Dew Point	DC (Thermopile and RTD)	DV (RTD)	DC (Photocell)
Combustible Gas	DC	DV (Catalyzed Sensor)	DV (Reference Sensor)
Flow (Thermistor)	DC	DV (Heater) Sensor)	DV (Reference Sensor)

(a) DC = Direct Current, DV = Direct Voltage, AC = Alternating Current, AV = Alternating Voltage.
(b) Does not include measurement of excitation (for ratio-metric measurements).

ıre 14 illustrates automatic correction of zero ana gains errors in S/C naraware. By sequentially applying two known voltages (zero and an accurate full-scale reference voltage) and measuring the respective S/C response to these inputs, an error-corrected measurement of an arbitrary input can then be taken by interpolation. The interpolation math is performed by the computer. No S/C calibration adjustments are required. Both initial and time/temperature induced errors can be compensated.

Sensor Calibration. Non-ideal sensors have unique gain and zero-offset values. They may approximate some nominal characteristic, but critical measurement usually require correction for sensor anomalies. With microcomputer aided S/C, sensor calibration constants are stored in electrically eraseable programmable read-only memory (EEPROM) which is equivalent to "digital potentiometers." Software calculations use these constants to correct for sensor anomalies. Where in situ sensor calibration is present, the contents of sensor EEPROM would be updated during each sensor calibration cycle.

Filtering. Low-pass filtering generally improves the signal-to-noise ratio of a measurement, the actual improvement depending upon filter characteristics and noise statistics. Filtering can be implemented in both analog and digital domains. With μP-based instruments, it is desirable from both cost and performance viewpoints to filter in the digital domain (either hardware or software).

Linearization. Non-linear sensors (e.g., thermistors) have traditionally interfaced to special analog circuits to linearize their measurement parameter to electrical output transfer functions. With computer-assisted S/C, software routines can correct for non-linearity instead. This allows the sensors to be connected to more generic (or universal) S/C.

Ratiometric Transducer Measurement. Some sensors require both electrical excitation and S/C. Excitation can take the form of voltage with bridge transducers, or current with resistance-type transducers. Traditionally, excitation is produced by a stable and accurate voltage/current source, something that can be sizeable and expensive. With computer-assisted S/C, the size and cost of excitation can be reduced by ratiometric measurement techniques. With this approach accurate excitation is no longer required. Instead, both the excitation and output signals are measured by the S/C, and the measured parameter is calculated by multiplying the ratio of output to excitation by the transducer transfer function. Figures 15 and 16 illustrate two examples of ratiometric measurements, one with a bridge transducer, the other with a resistance transducer.

Universal S/C and Excitation

As noted above, most sensors in ECLSS subsystems utilize DC voltage or current excitation and S/C. They are therefore amenable to programmable gain S/C methods. In the area of excitation, there is even less variation of electrical levels between sensor types. This suggests a common approach to voltage/current excitation with minimal need for programming. Universal approaches to hardware design reduce spares inventory and simplifies maintenance. By itself, however, this concept does not necessarily reduce size.

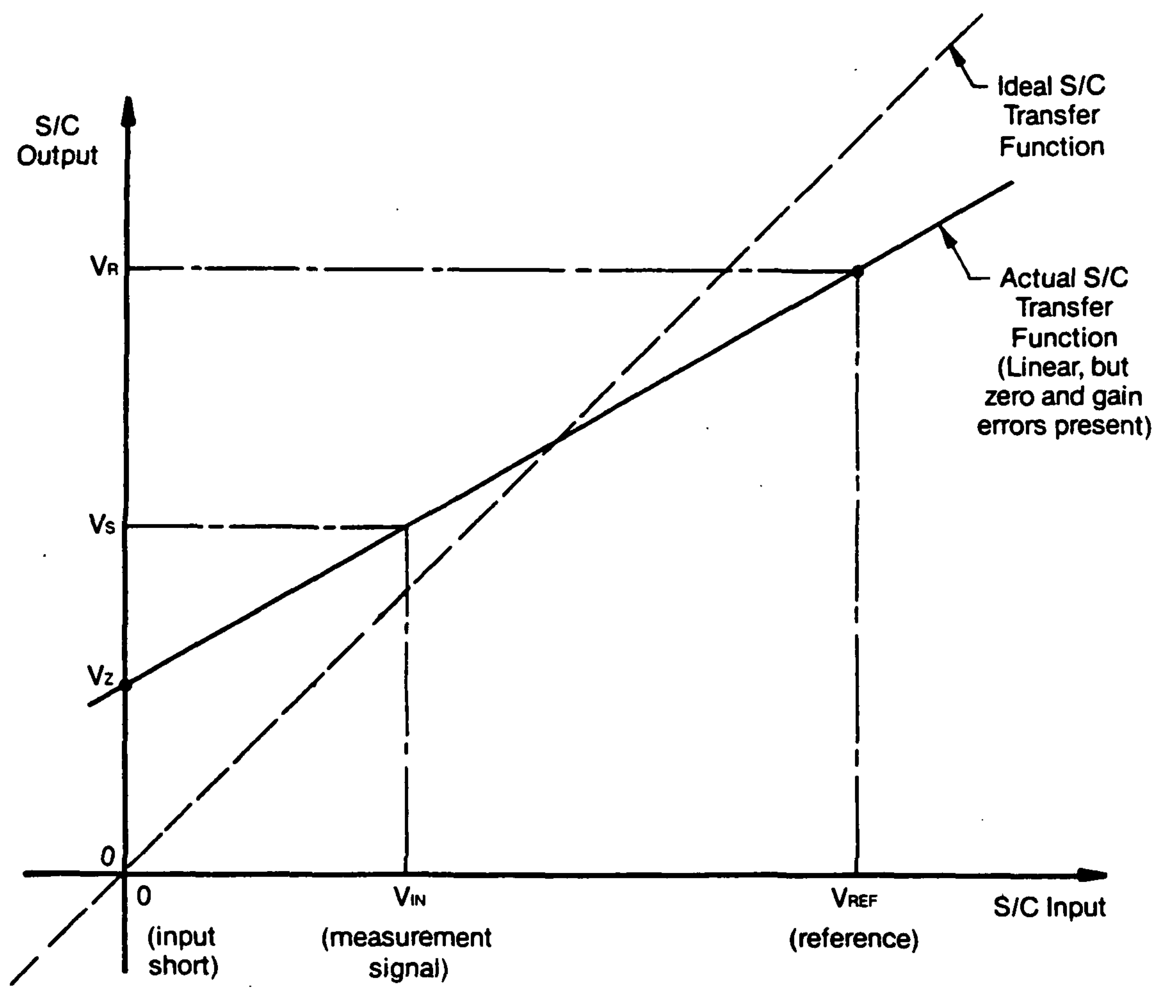
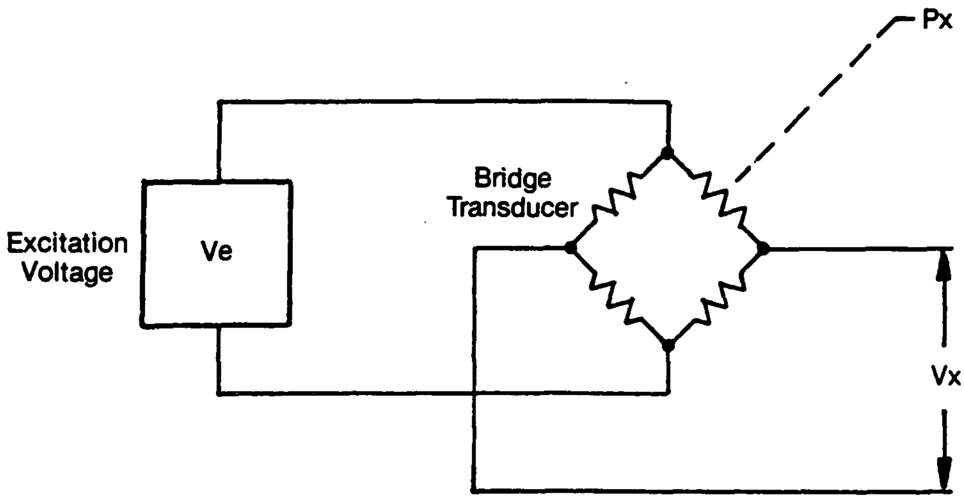
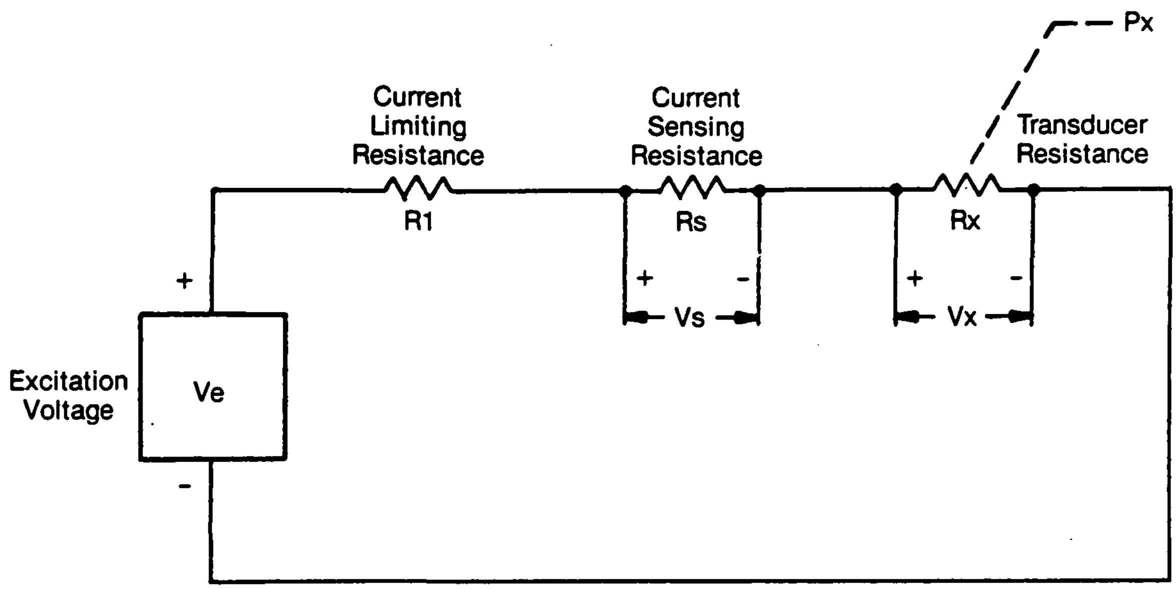


FIGURE 14 AUTOMATIC CALIBRATION



Px = Physical parameter being measured
k = Bridge constant
Ve = Excitation voltage
Vx = Bridge output voltage

FIGURE 15 RATIOMETRIC MEASUREMENT - BRIDGE TRANSDUCER



Px = Physical parameter being measured
Ve = Excitation Voltage
Vx = Output Voltage

FIGURE 16 RATIOMETRIC MEASUREMENT - RESISTANCE TRANSDUCER

Sensors with special excitation/measurement requirements that are incompatible with 'universal' types of S/C must be handled with dedicated S/C as before. In some applications alternative sensors are available that will make the desired measurement and will interface to universal S/C (e.g., linear potentiometers instead of linear variable differential transformers (LVDTs)) or to the C/M I computer (e.g., a digital Hall-effect proximity switch in place of a variable-reluctance speed sensor).

Pre-S/C Multiplexing

In both of Life Systems' Series 100 and 200 C/M Is, inputs were conditioned with sensor-dedicated circuits prior to multiplexing and digitization (Figure 17). With a universal approach to S/C, however, it is possible to move the multiplexer ahead of the S/C (Figure 18), replacing the sensor-dedicated S/C blocks with a single universal S/C. Depending upon sensor count and complement, pre-S/C multiplexing has potential for significant S/C size reduction.

Pre-S/C multiplexing implies:

1. 'Universal' multiplexing - the ability to handle both high and low level unconditioned inputs. Error voltages (e.g., thermals) must be low (compared to signal measurement resolution), and protection must be in place to prevent damage from over-voltage inputs (e.g., from mechanical subsystem faults). Switching device speeds must be adequate to handle desired multiplexing rates.

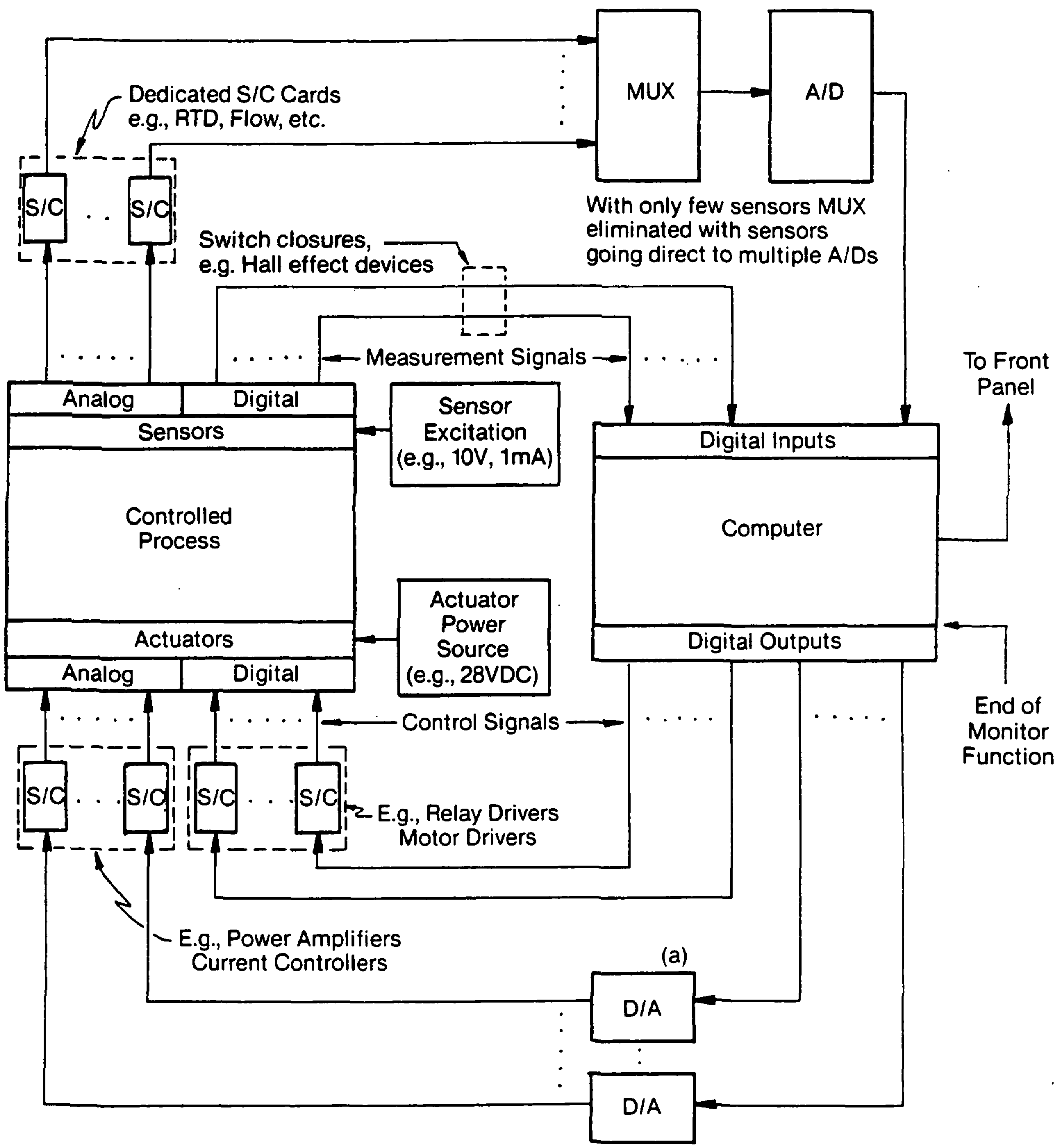
2. Software programmed S/C gain - with a single S/C time-shared between all sensors, gain must be re-programmed as different sensor types are multiplexed into the S/C.

3. Wideband S/C required - bandwidth requirements are driven by multiplexing rates rather than sensor speeds as is the case with sensor-dedicated S/C. Signals multiplexed into the S/C must settle to the required accuracy limits within the time that the signal remains connected. Wide bandwidth opens the issues of electromagnetic interference (EMI) susceptibility and internally generated noise.

Fault Detection, Isolation and Correction

Figure 19 illustrates a redundant implementation of an advanced concept S/C architecture. The S/C and A/D cards are duplicated and interconnected (cross-strapping), while sufficient multiplexer cards are installed so that every sensor can connect redundantly to two or more multiplexer cards.

Within each S/C block a reference voltage is provided for auto-calibration. The reference also serves as a known stimulus for self-checking of the analog S/C and A/D. Under computer control, either reference can be selected by any single multiplexer block, conditioned by either S/C block and then digitized by either A/D. As shown in the example of Figure 19, either reference can take any of 16 possible pathways to the computer (4 Mux x 2 S/C x 2 A/D). With two reference voltages, 32 pathways can be self-checked.



a. Demuxing from a single D/A usually impractical because certain actuators (e.g., current controllers) require continuous drive.

FIGURE 17 TRADITIONAL C/M I ARCHITECTURE SHOWING EXAMPLE COMPONENTS

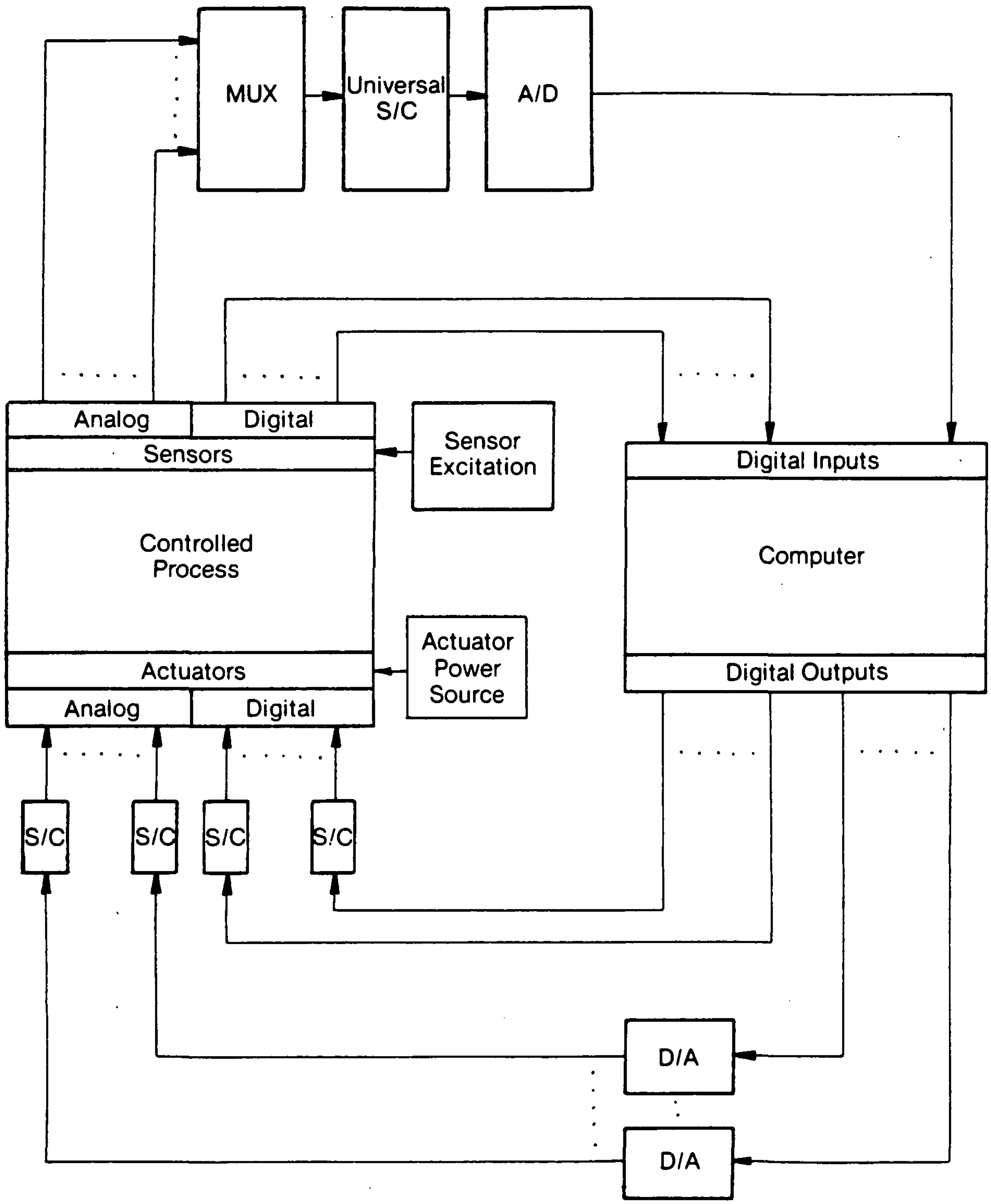
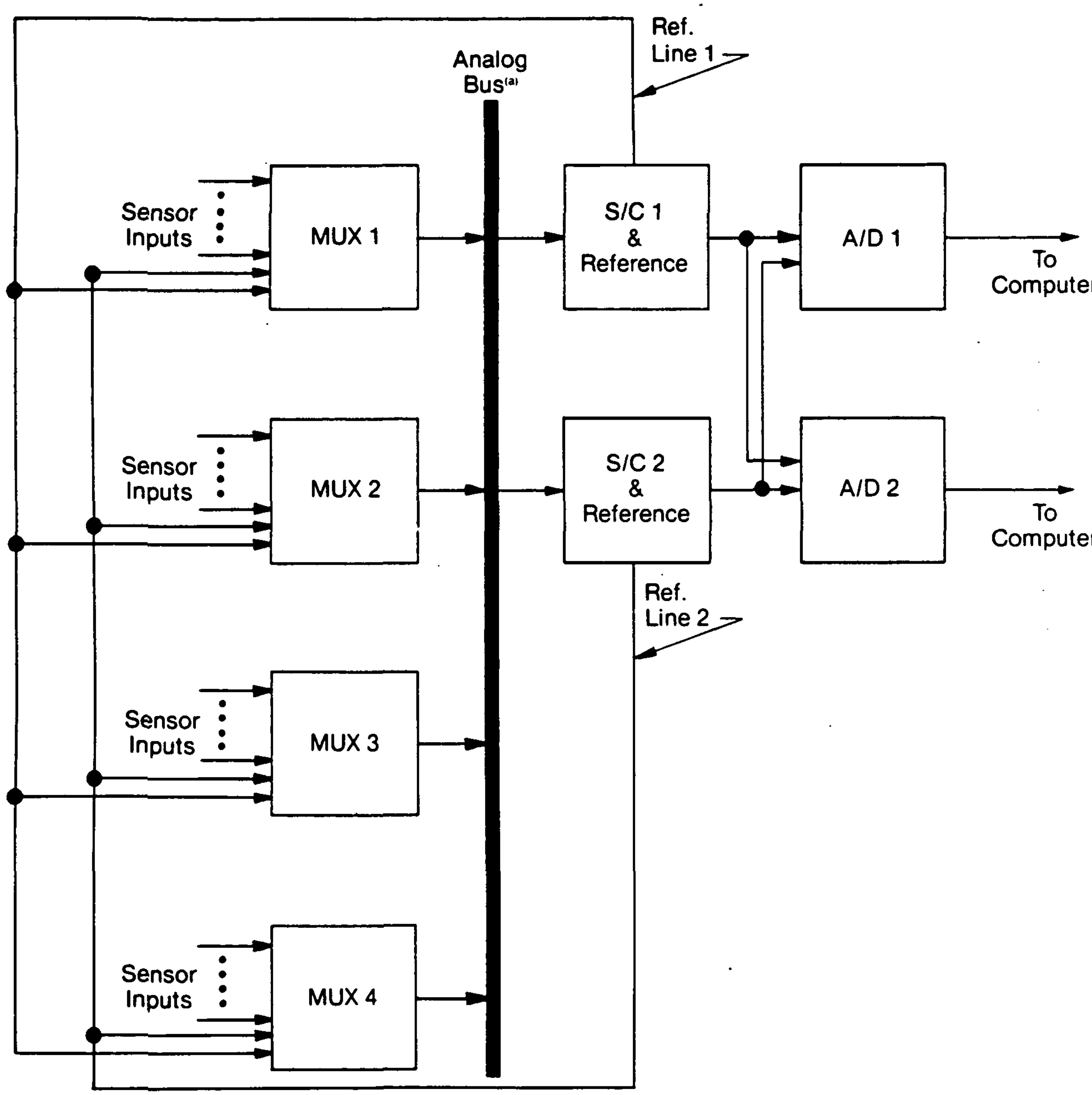


FIGURE 18 PRE-SIGNAL CONDITIONING MULTIPLEXING



(a) 16 MUX Capacity (256 Channels).

FIGURE 19 REDUNDANT S/C IMPLEMENTATION FOR FAULT DETECTION

Where faults exist in one or more blocks, several self-check pathways will yield erroneous reference readings, thus detecting that a fault condition exists. Exhaustive checking of all possible pathways by appropriate fault-location software, will isolate the source of the fault.

Self-check has its limits though. If all blocks of a single type have failed (e.g., two defective A/Ds) it is impossible to locate a fault since all self-check pathways yield faulty readings. Also, multiplexer self-testing is limited to the common circuitry that is shared by all inputs. Circuitry that is unique to each sensor input cannot be checked using the reference as a stimulus. However, with sensors wired to multiple inputs, voting logic can isolate defective inputs. Faults within sensors themselves can be isolated, by voting between redundant sensors or in situ calibration.

Once the computer has located the source of a S/C fault, its next action is to disconnect faulty blocks (Figure 20). Subsequent readings are then taken via pathways that circumvent the isolated faults (Figure 21).

Galvanic Isolation

In S/C terminology, the concept of isolation is a galvanic barrier through which signals can pass without electrical connections being present. This is accomplished by converting electrical signals to another energy form (e.g., optical, magnetic, ultrasonic) prior to transmission, and then converting the received energy back to electrical form. In a similar manner, electrical power can be passed through such barriers.

Benefits derived from extensive use of such barriers in S/C include:

- Ability to measure low-level signals in the presence of high-level common-mode voltages (e.g., DC potentials, power-line pickup, EMI)

- Fault conditions appearing as common-mode voltages are not propagated

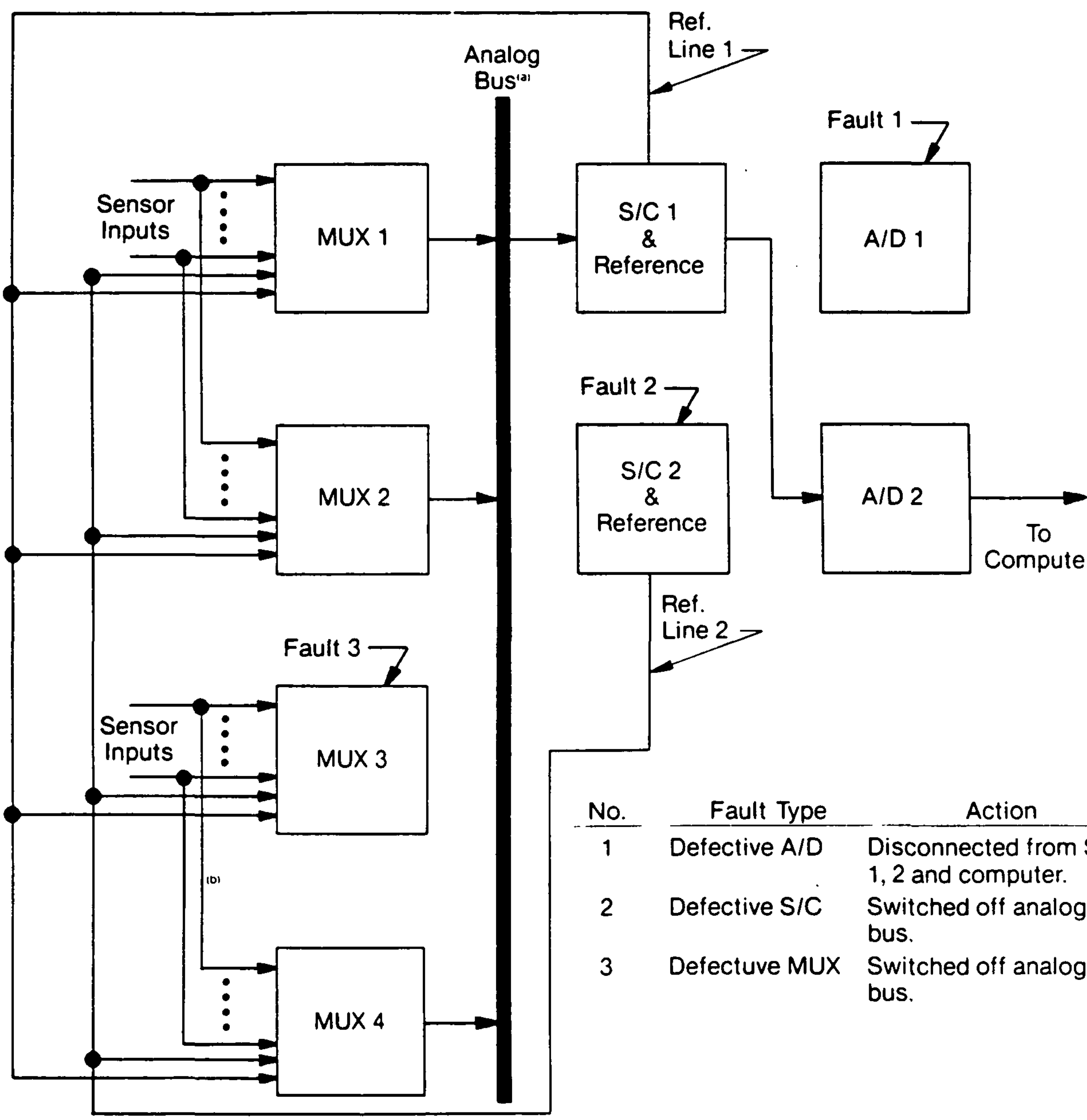
- Fault conditions appearing as normal mode (i.e., differential) voltages are propagated at nondestructive levels

- Ground-loops caused by failures can be broken

In summary, isolation barriers permit the measurement of signals in the presence of noise and/or large potentials that would otherwise disable instrumentation. Furthermore, they protect following circuits from damage from electrical faults, either internal to the S/C or external.

The most complete implementation of galvanic isolation in S/C is three-port isolation. The ports are input, output and power, respectively. Three-port isolation places galvanic barriers between all three ports.

Isolation between input and output ports is implemented with an isolation amplifier. Hybrid isolation amplifiers based on magnetic and optical techniques are available. Magnetic amplifiers are more accurate, but suffer



No.	Fault Type	Action
1	Defective A/D	Disconnected from S/C 1, 2 and computer.
2	Defective S/C	Switched off analog bus.
3	Defectuve MUX	Switched off analog bus.

(a) 16 MUX Capacity (256 Channels).
(b) Any level up to 16 redundancy possible.

FIGURE 20 FAULT ISOLATION EXAMPLE

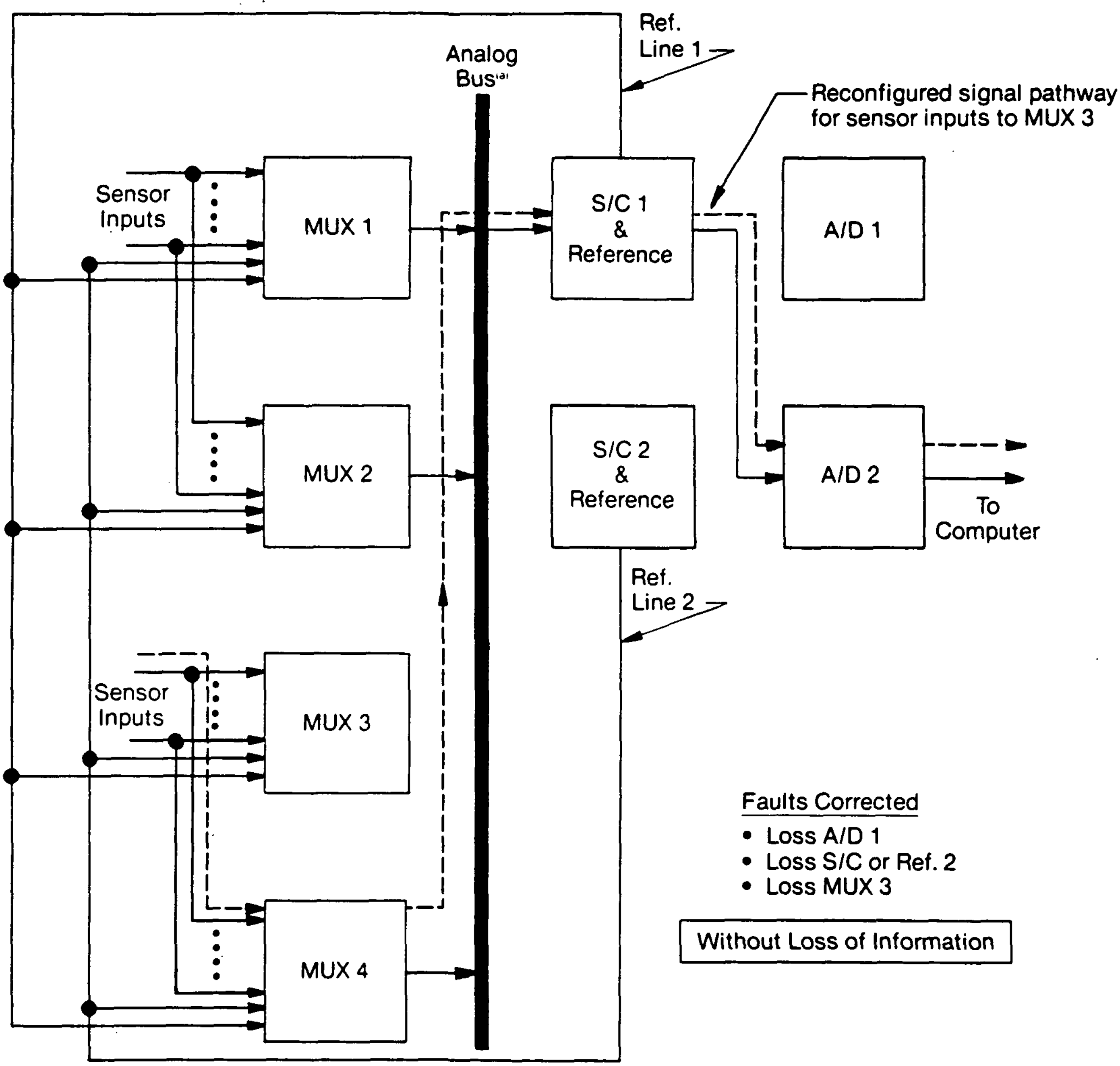


FIGURE 21 FAULT CORRECTION EXAMPLE

from relatively low bandwidth ($\sim$2 kHz) and a tendency to radiate EMI unless shielded. With automatic correction of gain/zero errors built into C/M I, the optical approach to signal isolation is the better choice.

Isolation between the signal pathway and power bus is implemented most cost and size effectively with DC-DC converters. These transmit power into S/C circuits via magnetic energy. More so than magnetic isolation amplifiers, DC-DC converters are a significant source of radiated and conducted EMI. Appropriate line filtering and shielding is usually required.

Packaging Options

Appropriate approaches to packaging (device integration and interconnection) facilitate both size reduction and reliability enhancement.

Device Integration. At the IC level (i.e., monolithic chip), analog components deliver the electrical performance of earlier generations of hybrid circuits at a fraction of the size and cost. Likewise, today's hybrids match the specifications of earlier modular components built from discrete devices, again with substantial size and cost reduction. At any time, discrete S/C hardware provides the ultimate in performance, but at the highest cost and size. Integrated circuits offer the lowest levels of performance, at the lowest cost and smallest size. Hybrids provide intermediate levels of performance, cost and size.

The performance capabilities of discrete analog circuits far exceed the needs of ECLSS C/M I. This approach to S/C is inappropriate. Hybrids readily provide the required performance levels. Since hybrids are essentially multiple chips within a single package, a sufficient quantity of monolithic devices can reproduce the performance characteristics of a hybrid. However, the overall size of multiple ICs is generally larger than the equivalent hybrid. Hybrid technology reduces part-count also, contributing to improved mean-time-between-failure (MTBF).

Hybrid circuits were used extensively in developing a breadboard of the advanced concept S/C. In all instances size reduction was achieved compared to using equivalent ICs. Other reasons also favored the hybrid choice:

a. Multiplexer - Hybrid opto-coupled field effect transistors (FETs) provide the switching speed and off-voltage rating required for pre-S/C multiplexing. Monolithics have inadequate over-voltage protection capability while reed relays are too slow.

b. Programmable Gain Amplifier - At this time only hybrids are capable of software programming. Monolithics require hardwire gain programming.

c. Reference - Hybrids come pretrimmed to tight tolerances that eliminate the need for additional calibration hardware. Furthermore, they achieve good temperature stability without the need for an on-board temperature-regulated heater. This reduces power consumption and extends MTBF.

d. Isolation Amplifier - The high common-mode voltage capabilities required of these components preclude monolithic technologies. Only hybrids meet the voltage and leakage current requirements of this application.

A brief investigation into A/D converters resulted in similar findings. Integrated circuit A/D converters are widely sourced, but combined with the required support devices (sample/hold circuit, clock, μP interface logic, etc.), the overall size is larger than an equivalent self-contained hybrid.

Device Interconnection. Compared to conventional double-sided printed circuit, multilayer and multiwire circuit board technologies increase the density of device interconnect wiring. This reduces the board 'real-estate' required for interconnects, and thus increases the density with which devices can be packed onto a circuit board. However, extensive use of hybrid circuits results in a majority of interconnects being removed from the circuit board and being placed within the hybrid package. For this reason multilayer/multiwire boards offer minimal additional improvement (maybe 10%) in device packing density. Furthermore, multilayer boards are difficult to impossible or repair, and suffer from a failure rate 100 times that of double-sided board. Multiwire technology is new, and its reliability is not documented in MIL-HDBK-217D, a standard reference for reliability prediction of electronic equipment.

The above factors strongly favored using double-sided printed circuit wiring for the generic S/C hardware.

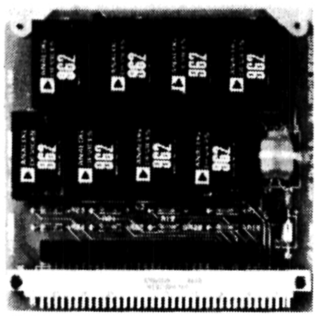
Generic S/C Hardware

Life Systems, with its own funding, initiated hardware development to verify the concepts generated under the program. Each of the four generic S/C cards have undergone several stages of development: design analysis, detail design, breadboard and test, printed circuit proof board and final printed circuit production board. They exist and have been checked out. Figure 22 shows the four cards while Figure 23 shows various packaging concepts for subsystems requiring one to four multiplexer cards.

Multiplexer Card

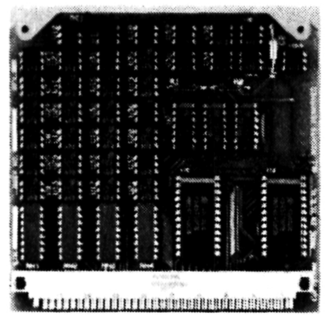
Signals from up to 16 sources connect to input channels. Selecting one of these inputs and connecting it to the multiplexer output involves closing pairs of analog switches. The analog switches are hybrid opto-coupled power FETs featuring voltage switching capability comparable to reed relays (250 V), but at switching speeds 2-10 times faster. Resistor networks limit fault current in the event that multiple analog switches fail in a shorted state, creating fault paths between two or more signal inputs.

A power input line inductor consists of radio-frequency (RF) chokes. Their phasing is such that they impede common-mode currents entering the card from the logic power supply (or vice versa). Capacitors attenuate normal-mode noise. These components appear on the other circuit cards and are one of several measures taken to minimize both EMI susceptibility and EMI generation (radiated and conducted).



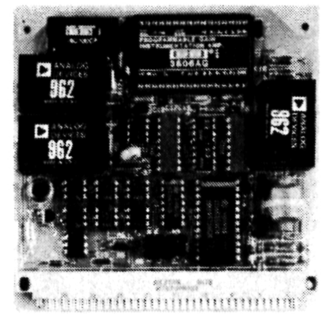
SENSOR EXCITATION

- Voltage Sources & Precision Resistances Externally Configured for Specific Sensors



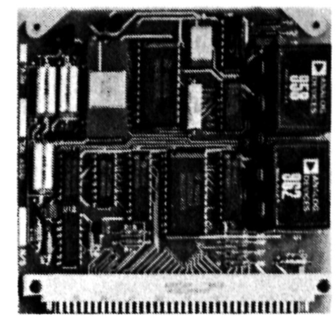
MULTIPLEXING

- 16 Differential Channels
- Solid State Optical Switches for Isolation, Speed & Reliability



SIGNAL CONDITIONING

- Programmable Gain (1, 2, 4, ..., 1024)
- Optically Isolated Amplification
- References for Auto-Calibration & Self Test

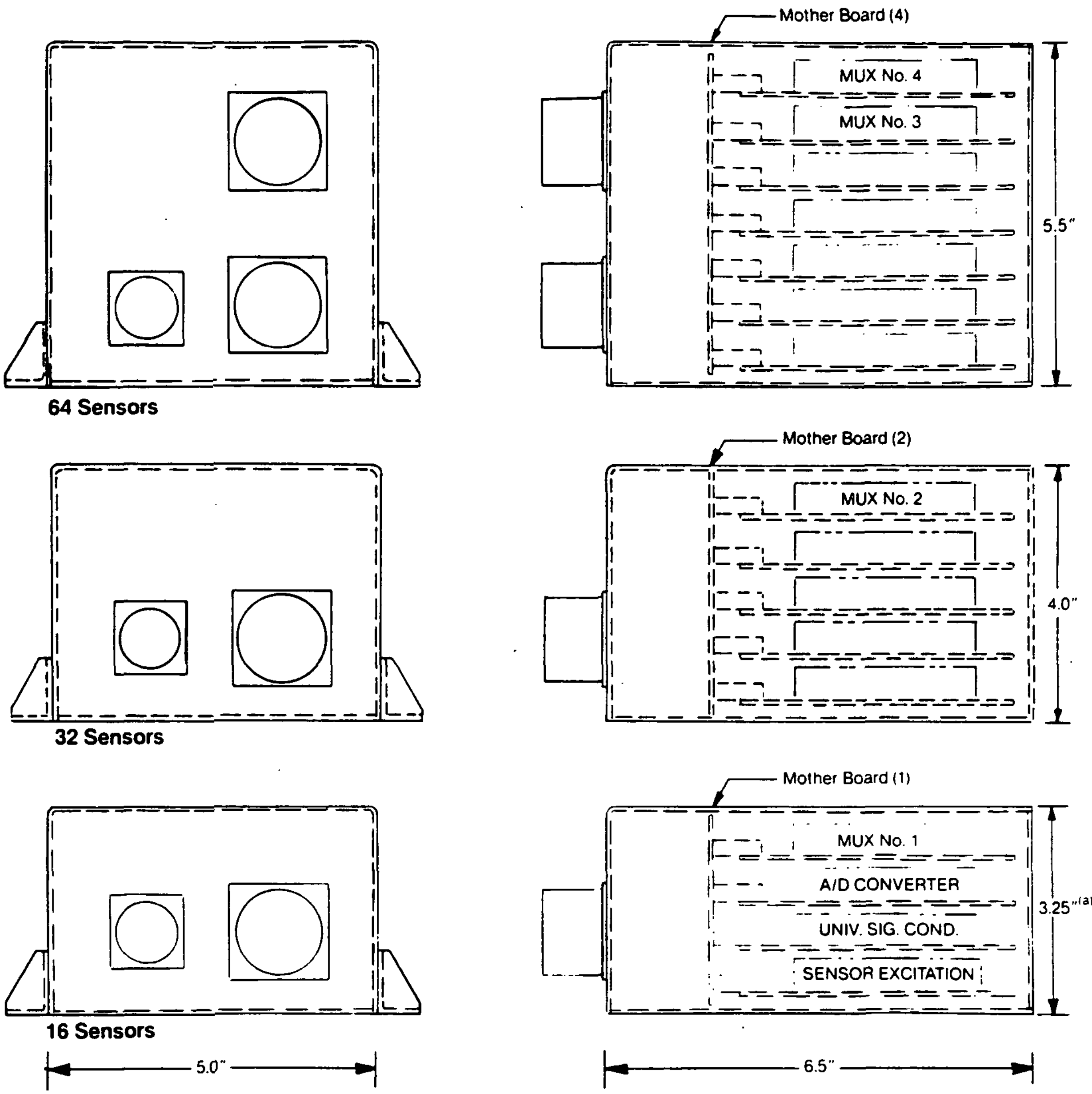


ANALOG-TO-DIGITAL CONVERSION

- Interface Between Computer I/O and Generic S/C (Serial Pathway)
- 12 Bit Converter

Card Size: 4.4 x 4.5 in

FIGURE 22 GENERIC SENSOR SIGNAL CONDITIONING PC CARDS



(a) Height increases 0.75 in/each MUX Card added.

FIGURE 23 GENERIC SIGNAL CONDITIONING PACKAGING CONCEPTS

Sensor Excitation Card

This card contains DC-DC converters, current sense resistors and current limiting resistors.

Each DC-DC converter independently supplies +5 V at 100 mA (maximum). This converter provides:

a. Voltage excitation in multiples of 5 V.

b. Current excitation using resistors to establish excitation magnitude.

c. Series combinations of two or more DC-DC converters which produce high voltages for special applications.

The primary function of the current sense resistors is excitation measurement rather than excitation adjustment. These are precision components used to monitor transducer excitation levels or convert current output sensor signals to voltages suitable for multiplexing.

The card contains current limiting resistors. These are used with resistance thermal devices (RTDs) and thermistors. Depending on the ECLSS application, various current limiting resistor values may be selected to perform current limiting.

Unversal S/C

The universal S/C consists of a programmable gain instrumentation amplifier (PGIA), an isolation amplifier, a reference voltage source, an attenuator to generate auto-calibration voltages, and analog switches that steer either signal or auto-calibration voltages into the instrumentation amplifier. Reference voltages are provided for the auto-gain function corresponding to various PGIA gain settings. Standard reference voltages of or reference-common are used. Reference-common connects to both PGIA inputs during auto-zero. All auto-calibration voltages are compensated for the voltage drop due to PGIA bias current.

Resistors limit fault current into the PGIA in the event of an external overload passing through the multiplexer. In conjunction with these resistors, capacitors form low-pass filters that attenuate high-frequency normal-mode and common-mode noise. Filtering is performed ahead of the PGIA due to its limited bandwidth compared to the frequency spectrum of potential radio frequency interference (RFI)/EMI noise sources. Noise components above the PGIA cutoff frequency would otherwise create DC error voltages due to input rectification or non-symmetrical output slewing.

A/D Converter and Computer Interface

This card serves two main purposes - accept S/C instructions from the C/M I computer, and provide digitized measurements to the computer. Instructions include signals that configure the S/C cards, and fault status information need to drive fault indicator light emitting diodes (LED)s.

The design of the A/D card was driven by the need to minimize the number of lines (wires) between the computer and the remotely located sensor S/C subassembly. Strictly serial I/O was not feasible because of insufficient PC card area for decoder/encoder hardware. An optimum compromise between line count and card area used a serial data out, parallel control in architecture. Inputs and outputs are 0/5 VDC complementry metal oxide semiconductor (CMOS) logic levels. Pullup resistors and buffers are provided to ensure compatibility with transistor-transistor-logic (TTL).

Overall throughput of data sampling is approximately 700 samples/sec and limited by the Mux switching, settling times in the PGIA and the A/D conversion period. Even for a large system (100 sensors) this rate is more than sufficient for sensor sampling required by ECLSS subsystems.

Other Issues

Mean-Time-Between-Failures

Following the procedures of MIL-HDBK-217D,[9] an estimate of the MTBF rate of the advanced concepts S/C was made. Vendors of special components (hybrids, DC-DC converters) were contacted for MTBF figures. Where these figures were not available, estimates were obtained from other vendors who manufactured similar devices. MTBF data on 'generic' components (resistors, capacitors, etc.) was provided by MIL-HDBK-217D. Without exception, the MTBF figures quoted by vendors were based upon a "fixed ground" application environment. MIL-HDBK-217D defines this as a less stringent environment than space flight (see Table 13).

Table 14 tabulates the failure rates (per 10^6 hours) of each type of component used in the advanced concepts S/C. Failure rates are based upon commercial grade components. A total of 110.26 failures is predicted for each 10^6 hours of operation, corresponding to a S/C MTBF estimate of 9,069 hours ($\sim$1.04 years). Military-grade design and processing of just the DC-DC converters and opto-FETs could extend this estimate to $\sim$5 years.

Breadboard Testing and Demonstration

The advanced S/C concepts were successfully demonstrated with a personal computer. The demonstration included:

a. Universal S/C - sensors include four types of temperature sensors, a bridge-type pressure transducer, cell voltage tabs, and a millivolt standard and decade resistance simulating voltage and resistance sensors respectively.
b. Conversion to engineering units.
c. Auto-calibration of both S/C and sensors.
d. Voting logic to detect loss of a triple redundant sensor.
e. Analog and digital formatting of display.

TABLE 13 ENVIRONMENTAL DESCRIPTIONS

Environment	Description[a]
Ground, Benign	Nonmobile, laboratory environment readily accessible to maintenance; includes laboratory instruments and test equipment, medical electronic equipment, business and scientific computer complexes.
Ground, Fixed	Conditions less than ideal such as installation in permanent racks with adequate cooling air and possible installation in unheated buildings; includes permanent installation of air traffic control, radar and communications facilities and missile silo ground support equipment.
Ground, Mobile	Equipment installed on wheeled or tracked vehicles, includes tactical missile ground support equipment, mobile communication equipment, tactical fire detection systems.
Space, Flight	Earth orbital. Approaches benign ground conditions. Vehicle neigher under powered flight nor in atmospheric reentry; includes satellites and shuttles.
Manpack	Portable electronic equipment being manually transported while in operation; includes portable field communications equipment and laser designations and rangefinders.

(a) MIL-HDBK-217D.

TABLE 14 COMMERCIAL GRADE S/C MTBF TABLE

Component	Quantity Mux	Exc	S/C	A/D	Total, N	$\lambda^{(a)}$	λN
Capacitor, Ceramic	1	1	11	7	20	0.066	1.32
Capacitor, Tantalum	1	1	8	4	14	0.2	2.8
Resistor, Film	33	8	20	11	72	0.003	0.216
Resistor, Bulk Alloy	-	16	4	-	20	0.1	2.0
Diode, Power	-	-	1	-	1	2.2	2.2
PGIA	-	-	1	-	1	$0.7^{(b)}$	0.7
Isolation Amplifier	-	-	1	-	1	$0.6^{(b)}$	0.6
DC-DC Converter	-	8	4	2	14	$3.7^{(b)}$	51.8
Opto-FET	34	-	7	-	41	$0.7^{(b)}$	28.7
Reference	-	-	1	-	1	$0.6^{(b)}$	0.6
Transformer, RF	1	1	1	-	3	0.08	0.24
Digital Opto-coupler	-	-	3	-	3	0.6	0.18
Digital Integrated Circuit	5	-	2	11	18	1.05	18.9
							110.26

(a) Component failure rate per million hours.
(b) Estimated from data available on similar components.

System Utilization

Table 15 is a historical summary of sensor S/C concepts for the EDC Subsystem. Advanced S/C concepts are incorporated into the proposed Series 300 C/M I projected for the three-person EDC (CS-3A) presently being developed.

CONCLUSIONS

The following conclusions are a direct result of the analysis and design activities of the advanced C/M I for flight application program.

1. The capabilities removed from the Series 100 C/M I, particularly the operator/user interface, has more than adequately been replaced with the PDU. Increased versatility and capability is provided by a software-based PDU to examine, store, change and output user commands for subsystem control and monitor.

2. The design of the PDU based on an intelligent computer terminal and a variety of STD printed circuit cards is cost-effective. Because of the wide availability of STD bus cards, any application and interface can be accommodated. The PDU will not be obsoleted by technology change.

3. The design of sensor signal conditioning based on four generic cards - multiplexer, excitation, universal S/C and A/D conversion - offers a radically new approach to subsystem sensor/computer interface. Reduction of part count, unique circuits and size results. The generic S/C approach now needs demonstration at the total integrated system level.

REFERENCES

1. Yang, P. Y.; See, G. G. and Yeh, J. Y., "A Minicomputer-Based Control and Monitor System for Water and Wastewater Treatment," Proceedings of the International Computer Symposium, 1977, Volume 2, pp. 856-859; Taipei, Republic of China; December, 1977.

2. Powell, J. D.; Schubert, F. H.; Marshall, R. D. and Shumar, J. W., "Six-Man, Self-Contained Carbon Dioxide Concentrator Subsystem," Final Report, Contract NAS2-6478, NASA CR-114743, ER-134-32; Life Systems, Inc., Cleveland, OH; June, 1974.

3. Schubert, F. H.; Hallick, T. M. and Koszenski, E. P., "Advanced Electrochemical Depolarized Concentrator Cell Development," Final Report, Contract NAS2-10204, NASA CR-166141, TR-379-4; Life Systems, Inc., Cleveland, OH; December, 1981.

4. Schubert, F. H.; Lee, M. K.; Davenport, R. J. and Quattrone, P. D., "Water Electrolysis System: H_2 and O_2 Generation," Paper 78-ENAs-3, presented at the Intersociety Conference on Environmental Systems, San Diego, CA; July, 1978.

TABLE 15 SUMMARY OF SENSOR SIGNAL CONDITIONING CHARACTERISTICS FOR EDC SUBSYSTEMS

Application Subsystem	C/M I Series: Hardwired: Exper. CX-1	Hardwired: 90-Day CX-6	Hardwired: SSP CS-6	100: RLSE CS-3	200: Prototype CS-1	300 Proj.: Tech. Demo. CS-3A
No. of Sensors	29	60	135	32	20	32
No. of S/C PC Types Reqd	6	6	8	7	7	4
Total PC Cards (monitor/ measurement)	30	22	21	11 +1 (A/D)	9 +2 (A/D)	5 +1 (A/D)
S/C Power	0.9 W per sensor (including lamp-logic)			0.3 W per sensor (<1.5 W per S/C card		0.3 W per sensor
Weight (excluding S/C overhead)	0.11 kg (0.25 lb) sensor (Based on one sensor/card, including lamp-logic)			0.023-0.11 kg (0.05-0.25 lb) sensor corresponding to 5-1 sensors per S/C card, respectively		0.01-0.02 kg (0.02-0.04 lb) sensor (correspond. to 26-8 sensors per MUX)
S/C Cost (low volume, commercial/industry grade devices[a]	~$100 per sensor (including lamp-logic)			~$50 per sensor (3 sensors/card)		$25-$50 per sensor ($400 per 16-channel MUX)
C/M I Architecture	• Monitoring with threshold comparators and lamp logic • Separate analog circuits for dedicated loop control (measurement and actuation)			• Control and monitor sensors conditioned with identical analog circuits • Unique S/C for each sensor type		• Pre-S/C MUX concept extended to most sensors • "Universal" S/C shared by sensors

continued-

(a) Mil/Space Spec. (MIL-STD-975) parts would increase values cited by about 5 to 20 times cited amounts.

Table 15 - continued

Application Subsystem	C/M I Series: Hardwired: Exper. CX-1	90-Day CX-6	SSP CS-6	100 RLSE CS-3	200 Prototype CS-1	300 Proj. Tech. Demo. CS-3A
				• One S/C circuit for each sensor (except cell-voltage) • Data converters (A/D, D/A) provided digital readouts and interfacing to mini/micro computer		• S/C hardware function programmed by μC • A/D function included in S/C
S/C "Overhead", i.e., CPU Interface and S/C Independent of Sensor Count	130 cm^3 (20 in^2) sensor			45 cm^2 (7 in^2)/sensor, (130 cm^2 (20 in^2)/ 3-sensor card)		8.1-16 cm^2 (1.25-2.5 in^2)/ sensor, 130 cm^2 (20 in^2)/16 channel MUX
S/C Output	Level Detector Outputs (Binary) • Caution • Warning • Alarm			0 to 5 V (Amplified and offset sensor output		0 to 5 V (Amplified sensor output)
IC Technology						
Digital:	TTL			TTL	TTL	TTL CMOS
Analog:	Bipolar			Bipolar	Bipolar	Bipolar Laser Trimmer Bipolar
Device Packaging Technology	Discrete, Monolithic			Discrete, Monolithic		Discrete, Monolithic, Hybrid

continued-

(a) Volume proportional to area with height typically 1.3 cm (0.5 in).

Table 15 - continued

Application Subsystem	C/M I Series: Hardwired, Exper. CX-1	Hardwired, 90-Day CX-6	Hardwired, SSP CS-6	100 RLSE CS-3	200 Prototype CS-1	300 Proj. Tech. Demo. CS-3A
Fault Detection	Trend and Fault analysis displayed with lamps			Demon. dynamic performance trend analysis	System/sensor status displayed on front panel	Yes, to S/C card level
Fault Isolation	No	Yes	No	No[a]	Implemented on redundant sensors	Yes, to card level
Fault Correction	Non-automatic. Required intervention of maintenance personnel			Maintenance provided (fault correction instruct.)	No	Automatic with redundant cards (i.e., fault tolerant)
Noise Rejection	No specified, but input noise does not affect sensor readout unless sensor output approaches a comparator setpoint			Analog filering implemented, not specified. Digital filtering by weighted averaging	Analog filtering implement. but, not specified	Analog: 80 dB CMRR (60 Hz) 120 dB NMRR (1 MHz) Digital: Optional

continued-

Table 15 - continued

Application Subsystem	C/M I Series					
	Hardwired			100	200	300 Proj.
	Exper. CX-1	90-Day CX-6	SSP CS-6	RLSE CS-3	Prototype CS-1	Tech. Demo. CS-3A
Reliability	Commercial 273 to 343 K (32 to 158 F) components. MTBF not calculated			Commercial 273 to 343 K (32 to 158 F) components. MTBF not calculated		"Extended" commercial 248 to 343 K (-13 to 158 F) MTBF to be calculated per MIL-HDBK-217D
MIL/Space Component Specifications	MIL/Space Versions available for parts used					No MIL/Space qualifications for off-the-shelf S/C hybrids
Maintenance	Periodic calibration required with long-term use (6-12 mon typical interval)					No routine maintenance
Calibration Technique	Threshold-comparator setpoint potentiometer			Zero and gain pots for normalization of S/C and sensor transfer functions		No manual adjustments. S/C controller performs auto-calibration of S/C. Sensor calibration constants stored in memory
Inter-Sensor Isolation	>100 volts (Reed-relay switches)			∿20 V (CMOS solid-state switches)		250 V (Opto-coupled power FETs)
Sensor-CPU Isolation	Not applicable			∿20 V		300 V

5. Yang, F. Y.; Schubert, F. H.; Gyorki, J. R. and Wynveen, R. A., "Advanced Instrumentation Concepts for Environmental Control Subsystems," Final Report, Contract NAS2-9251, NASA CR-152100, ER-309-6; Life Systems, Inc., Cleveland, OH; June, 1978.

6. Yang, P. Y.; Gyorki, J. R. and Wynveen, R. A., "Instrumentation for Controlling and Monitoring Environmental Control and Life Support Systems," Paper 78-ENAs-40, presented at the Intersociety Conference on Environmental Systems, San Diego, CA; July, 1978.

7. Yang, P. Y.; You, K. C.; Wynveen, R. A. and Powell, J. D., "Fault Diagnostic Instrumentation Design for Environmental Control and Life Support Systems," Final Report, Contract NAS2-10050, NASA CR-152039, TR-361-5; Life Systems, Inc., Cleveland, OH; October, 1979.

8. Heppner, D. B.; Dahlhausen, M. J. and Klimas, R., "Advanced CO_2 Removal Process Control and Monitor Instrumentation Development," Final Report, Contract NAS2-10674, TR-427-4; Life Systems, Inc., Cleveland, OH; January, 1982.

9. MIL-HDBK-217D, "Reliability Prediction of Electronic Equipment;" January, 1982.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-177378		

4. Title and Subtitle
ADVANCED LIFE SUPPORT CONTROL/MONITOR INSTRUMENTATION CONCEPTS FOR FLIGHT APPLICATION
Final Report

5. Report Date
March 1986

6. Performing Organization Code

7. Author(s)
D. B. Heppner, M. J. Dahlhausen and R. B. Fell

8. Performing Organization Report No.
LSI TR-596-28

9. Performing Organization Name and Address
Life Systems, Inc.
24755 Highpoint Road
Cleveland, OH 44122

10. Work Unit No.
T-6936

11. Contract or Grant No.
NAS2-11758

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Ames Research Center
Moffett Field, CA 94035

13. Type of Report and Period Covered
Contractor Report
11/83 - 06/85

14. Sponsoring Agency Code
506-64-31

15. Supplementary Notes
Point of Contact: Technical Monitor, Ted Wydeven, Jr., MS 239-4
Ames Research Center, Moffett Field, CA 94035
(415) 694-5738

16. Abstract
Development of regenerative Environmental Control/Life Support Systems requires instrumentation characteristics which evolve with successive development phases. As the development phase moves toward flight hardware, the system availability becomes an important design aspect which requires high reliability and maintainability. This program was directed toward instrumentation designs which incorporate features compatible with anticipated flight requirements. The first task consisted of the design, fabrication and test of a Performance Diagnostic Unit. In interfacing with a subsystem's instrumentation, the Performance Diagnostic Unit is capable of determining faulty operation and components within a subsystem, perform on-line diagnostics of what maintenance is needed and accept historical status on subsystem performance as such information is retained in the memory of a subsystem's computerized controller.

The second focus was development and demonstration of analog signal conditioning concepts which reduce the weight, power, volume, cost and maintenance and improve the reliability of this key assembly of advanced life support instrumentation. The approach was to develop a generic set of signal conditioning elements or cards which can be configured to fit various subsystems. Four generic sensor signal conditioning cards were identified as being required to handle more than 90% of the sensors encountered in life support systems. Under company funding, these were detail designed, built and successfully tested.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Computerized Instrumentation, Signal Conditioning Operator/System Interface	Unclassified - Unlimited Subject Category 54

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	72	

*For sale by the National Technical Information Service, Springfield, Virginia 22161